

T. Vigod

CONSOLIDATED HEARINGS BOARD

IN THE MATTER OF Sections 2 and 3 and 6 (3) of the Consolidated Hearings Act, 1981, S.O. 1981, c.20;

— and —

IN THE MATTER OF Section 12(2) of the Environmental Assessment Act, R.S.O. 1980, c.140;

— and —

IN THE MATTER OF Sections 30, 35 and 38 of the Environmental Protection Act, R.S.O. 1980, c.141, as amended;

— and —

IN THE MATTER OF Sections 24 and 61 (2) of the Ontario Water Resources Act, R.S.O. 1980, c.361, as amended;

— and —

IN THE MATTER OF Section 28 (3) of, and Regulation 164 under, the Conservation Authorities Act, R.S.O. 1980, c.85, as amended;

— and —

IN THE MATTER OF Section 40(12) of the Planning Act, S.O. 1983, c.1, as amended; in connection with site plan control of the sanitary landfill site;

— and —

IN THE MATTER OF Section 22(1) of the Planning Act, 1983 in connection with a referral to this Board by the Honourable Bernard Grandmaitre, Minister of Municipal Affairs, on a request by the Regional Municipality of Halton to amend the Official Plan for the Town of Milton to redesignate a parcel of land comprising Part Lots 3 and 4, Concession 2 N.S. in the Town of Milton from "Agriculture" and "Conservation and Hazard Lands" to permit the construction, operation and maintenance of a landfill site, Minister's File No. 24-OP-0208-A01;

— and —

IN THE MATTER OF Section 34(11) of the Planning Act, 1983 in connection with an appeal to this Board by the Regional Municipality of Halton for an order directing an amendment to By-law 61-85 of the Town of Milton to rezone the lands situated at Lot 3 and part of Lot 4, Concession 2 N.S., in the Town of Milton from "Agriculture" to permit a regional sanitary landfill site and ancillary uses;

— and —

IN THE MATTER OF Section 15(1) of the Planning Act, R.S.O. 1980 ch.379 in connection with a referral by the Honourable Claude F. Bennett, Minister of Housing on a request by Tremaine Britannia Citizen's Group for consideration of part of the Official Plan for the Halton Planning Area with respect to Sections 1 to 5 inclusive, 7, 9 and 10 of Part III D3 Solid Waste Management, Minister's File No. OPC-0026;

— and —

IN THE MATTER OF Section 64 of the Ontario Municipal Board Act, R.S.O. 1980, c.347 as amended in connection with an application by the Regional Municipality of Halton for an order approving:

a) the acquisition of land for the construction, operation and maintenance of a sanitary landfill site to contain 7.96 million cubic metres of waste in the Regional Municipality of Halton and to do so by one of two alternative methods as follows:

- (i) landfilling at the site referred to in Halton's Environmental Assessment as Site F in the City of Burlington;
- (ii) landfilling at the site commonly referred to in Halton's Environmental Assessment as Site D in the Town of Milton

at an estimated cost of \$12,775,000.00, and the borrowing of money by way of temporary advances not exceeding in the aggregate such estimated cost pending the sale of debentures, and

(b) the issuance of necessary debentures to a maximum of \$12,775,000.00 for a term not to exceed fifteen years;

— and —

IN THE MATTER OF Section 193(5) and Paragraph 84 of Section 210 of the Municipal Act, R.S.O. 1980, c.302, as amended;

— and —

IN THE MATTER OF Sections 6, 7 and 8 of the Expropriations Act, R.S.O. 1980, c.148;

— and —

IN THE MATTER OF an undertaking of the Regional Municipality of Halton to provide facilities for the purpose of receiving, dumping and disposing of waste as required by section 137 of the REGIONAL MUNICIPALITY OF HALTON ACT, R.S.O. 1980, c.436, as amended, by acquiring the land for, constructing, operating and maintaining a landfill to contain 7.96 million cubic metres of waste in the Regional Municipality of Halton.

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I N D E X

Witnesses:

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CHARLESWORTH, Dr. David Leonard (resumed)

Examination in chief by Mr. Estrin  
(cont'd)

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BEFORE:

H. H. Lancaster, Q.C. - Chairman

Dr. D. J. Kingham - Member



Hearing conducted at The Oakville  
Granary Commercial Centre, 105 Robinson  
Street, Oakville, Ontario, on Tuesday,  
January 26, 1988

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VOLUME 80  
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APPEARANCES:

|                                                 |                                                                                             |
|-------------------------------------------------|---------------------------------------------------------------------------------------------|
| T.R. Lederer and<br>H.D. Hodgson                | for the Regional<br>Municipality of Halton<br>(Proponent)                                   |
| J.R. Tidball                                    | for the Ministry of the<br>Environment                                                      |
| T. Vigod<br>J.F. Castrilli                      | for the West Burlington<br>Citizens Group                                                   |
| D. Estrin,<br>F.E. Leitch and<br>H. Dahme       | for the Corporation of the<br>Town of Milton                                                |
| S.R. Garrod and<br>A. Nurvo                     | for the Milton Area Citizens<br>Coalition and several<br>affected Milton area<br>landowners |
| R.B. Tuer, Q.C.<br>E.A. Cronk and<br>F. Perrier | for National Sewer Pipe<br>Limited                                                          |
| L.F. Longo                                      | for Azova Investments<br>Limited                                                            |
| M.J. McQuaid, Q.C.<br>and C.J. Tzekas           | for the City of Burlington                                                                  |
| C. Mansfield                                    | for the Ministry of Natural<br>Resources                                                    |
| P. Renaud                                       | for Cumis Limited                                                                           |



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APPEARANCES (Cont'd):

|    |              |                         |
|----|--------------|-------------------------|
| 1  | C. Stevenson | for Framgard Holdings,  |
| 2  | P. Hancock   | Fosseri Investments     |
| 3  |              | Limited, Seriphos       |
| 4  |              | Investments Limited and |
| 5  | J.H. Olah    | Topic Investments       |
| 6  |              |                         |
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Per: P. D. McQueen



Oakville, Ontario  
January 26, 1988

1 --- Upon commencing at 9:30 a.m.

2 MR. LANCASTER: Good morning. Please be  
3 seated.

4 DR. RONALD KERRY ROWE, (resumed):

5 DR. DAVID LEONARD CHARLESWORTH, (resumed):

6 EXAMINATION IN CHIEF BY MR. ESTRIN, (continued):

7 MR. ESTRIN: This morning we are going  
8 to finish Dr. Charlesworth's initial portion of  
9 evidence with regard to Site F and then go into  
10 Dr. Rowe probably in about an hour or so.

11 Q. First of all, I would like to deal  
12 with some aspects of your witness statement,  
13 Dr. Charlesworth, that is Exhibit 444, the joint  
14 witness statement. First of all, turn to paragraph 16  
15 and the issue that is going to be addressed here is the  
16 potential for migration of leachate at Site F in the  
17 weathered shale. This is a matter that came up in  
18 earlier discussions with Mr. Feenstra. I wanted you to  
19 give the Board your views on whether or not (a)  
20 leachate may indeed migrate to the weathered shale and  
21 (b) if it does, what can be done with regard to that.

22 DR. CHARLESWORTH: A. Yes, I believe  
23 that there is the potential for that movement just as I  
24 described in my very shallow system which reappears on  
25 site, the very shallow flow which will only flow for



1 relatively short distances within the ground before  
2 reappearing as seepages. I indicated we had seen some  
3 evidence in the site of seepages. So, I feel that that  
4 is a process which can occur with regard to leachate as  
5 well, obviously. Given that it is a localized  
6 phenomenon on the site it can be intercepted by toe  
7 drains.

8 Q. Toe drains, in the witness  
9 statement, my office spelled wrong; T-O-W instead of  
10 T-O-E. You would agree?

11 A. I would agree, yes.

12 Q. In fact, what about toe drains  
13 having been installed at Bayview and Burlington?

14 A. Yes, they have been installed now  
15 and the evidence indicates that they are effectively  
16 intercepting these shallow seepages.

17 Q. Now, the next paragraph of the  
18 witness statement I want to refer you to is paragraph  
19 20. I think we touched on this general area yesterday  
20 but paragraph 20 is with regard to Ms Hewetson's thesis  
21 and Mr. Feenstra's discussion in relation to it, to the  
22 effect that there is no basis to conclude that  
23 contaminants recorded by her south of Bayview Park are  
24 due to landfilling. We have already talked about that  
25 very briefly yesterday but can you perhaps deal with



1 this particular aspect of the likelihood or  
2 unlikelihood of the volatile organic chemical  
3 concentrations to the extent they were detected being  
4 the result of other sources of contamination such as  
5 solvents used in construction of piezometers or  
6 inadequately cleaned pipes as was discussed with  
7 Mr. Feenstra based on your experience?

8 A. I would agree with the discussion  
9 I read in the transcript of Mr. Feenstra's testimony  
10 that relatively low levels of three common organic  
11 chemicals were referenced or reported by Hewetson and  
12 that these could be present from a number of sources  
13 and were not indicative of contamination from the  
14 landfill. I believe that Mr. Feenstra also referred to  
15 the fact that at the time these installations were put  
16 in, the Waterloo holes and the Morrison, Beatty holes,  
17 the practices in the field of installing piezometers  
18 were not as rigorous as they are now if you are going  
19 to be monitoring for these kinds of volatile organics.  
20 That could be another possible source.

21 Q. You were around in those earlier  
22 days?

23 A. I am speaking from experience  
24 there. We were in those days using solvents to glue  
25 the couplings and we were not going to the rigorous



1 lengths that are done now to clean the piezometers  
2 before they are installed or to clean the augers  
3 between holes or the drill bits, et cetera. So I think  
4 that is a very reasonable statement that Mr. Feenstra  
5 made there, the conclusions that he drew.  
6

7 He also referred to Ms Hewetson's  
8 background holes and her explanation that these were  
9 possibly due to contamination from the landfill having  
10 sort of flowed backwards, not actually flowing uphill  
11 but flowing down in the ground, but in the opposite way  
12 to the topographic slope. He referred to the elevation  
13 of the water in the piezometer at that location and the  
14 elevation of the leachate in the landfill and indicated  
15 it was a higher head at the background hole and  
16 therefore it was unlikely that the contaminants could  
17 have moved essentially northwards from the landfill to  
18 the Waterloo background hole. I checked those levels  
19 and agree with his conclusions.  
20

21 Q. You conclude your paragraph --  
22 paragraph 20 of the witness statement refers to  
23 Mr. Feenstra's witness statement at pages 15 and 16 and  
24 sets out the proposition. You would indicate there is  
25 no basis to conclude that the contaminants reported by  
her were due to landfilling?

A. That is my opinion, Mr. Chairman.



1 Q. Now, I would like to turn to  
2 paragraph 68 of your witness statement. This is on the  
3 topic of the Ministry of the Environment Reasonable Use  
4 Policy and it is Exhibit E-154. The Board may wish to  
5 pull that out.

6 We have already touched on the first  
7 part of 68(a) of the witness statement. I am really  
8 directing your attention, Dr. Charlesworth, to  
9 paragraph 68(b) of the witness statement of Exhibit  
10 M-444. You have, I take it, examined the Ministry of  
11 the Environment Reasonable Use Policy?

12 A. Yes, I have.

13 Q. What can you say to the Board with  
14 respect to its policies and discussions essentially  
15 relevant to Site F?

16 A. I particularly had in mind here  
17 the statement at the bottom of page 8 of -- at least  
18 page 8 of my copy of the document.

19 Q. This is 154. In referring to page  
20 8 he is referring -- there are some preliminary pages  
21 which are not part of the reasonable use policy.

22 A. My attention was particularly  
23 drawn to the last sentence on that page which -- it is  
24 referring to the Ministry under the heading of "The  
25 Ministry's Responsibilities and Authority." Starting:



1 "To this end the Ministry may wish to  
2 discourage the use of some environments  
3 for waste disposal and to encourage the  
4 use of other environments."  
5

6 Referring back to the statement I made yesterday which  
7 is covered in the witness statement here, in paragraph  
8 (a), I feel that the poor quality of the groundwater at  
9 this location for which I see no other reasonable use  
10 would make this particular sentence on page 8 very  
11 appropriate to Site F. It is the kind of environment  
12 in which I think they may encourage the use for waste  
13 disposal.

14 Q. The discussion continues in that  
15 paragraph at the bottom of page 8 to the top of page  
16 10:

17 "The Ministry position is that waste  
18 disposal sites should be placed in  
19 environments where their impact will be  
20 minimized."

21 Again, could you give the Board your opinion about the  
22 relevance of that policy, position?

23 A. Yes, I believe that that is  
24 entirely relevant to Site F and as I also stated  
25 yesterday, I think we are in the fortunate position  
here that not only can we say that we believe that to



1 be likely when Site F goes in but on the basis of the  
2 performance of the existing sites, we have something  
3 more concrete to base it on.

4 Q. Now, having regard to what we know  
5 about the saline groundwater under Site F, can you  
6 comment with respect to the general concept of this  
7 document, the reasonable use policy, as you interpret  
8 it? Let us back up.

9 At Site D which we will be discussing  
10 and we have already heard evidence that there are  
11 people using wells in close proximity?

12 A. That is correct.

13 Q. We have heard some evidence from  
14 Mr. Sobanski that chloride levels and maybe a couple of  
15 other parameters are either at or above Ministry of the  
16 Environment drinking water guidelines in a couple of  
17 instances of those wells. Can you very briefly comment  
18 on the applicability of the reasonable use policy to  
19 those facts and then comment on its applicability, if  
20 any, really to Site F?

21 A. I think it will become obvious --  
22 it has become obvious from the testimony of  
23 Mr. Sobanski as well that the conditions in terms of  
24 groundwater quality are entirely different at the two  
25 sites. It is my contention that at Site D, there can



1 be no additional increase in various parameters because  
2 you would be in violation of the reasonable use  
3 concept, the reasonable use guidelines. However, Site  
4 F falls into a different category within the reasonable  
5 use guideline. On that basis I believe it to be an  
6 acceptable site for waste disposal.

7 Q. While we are on this same topic I  
8 wanted to refer you to Exhibit M-160 which is a paper  
9 by Dr. Cherry and others on the topic, "The  
10 Hydrogeologic Aspects of Landfill Impacts on  
11 Groundwater and the Regulatory Implications." You have  
12 seen this paper before?

13 A. I have seen this paper before.

14 Q. Now, in particular I wanted to  
15 refer you to the page numbers that have been  
16 obliterated. It is the second-last page of the text  
17 just before the references. There is a number 52 on  
18 the page I am looking at in a circle at least on my  
19 copy.

20 MR. LANCASTER: That is the penned-in  
21 number.

22 MR. ESTRIN: There is a heading partway  
23 down the page, "Implications."

24 Q. I wanted to direct your attention  
25 in particular, Dr. Charlesworth, to item No. 4,



1 beginning at the bottom of the page. Would you just  
2 read that, please?

3 A. "At the present time landfilling  
4 is an unavoidable means of disposing of  
5 most municipal waste. Also eventual  
6 off-site migration of contaminants is  
7 an unavoidable consequence of  
8 landfilling in nearly all types of  
9 hydrogeological settings. It is  
10 desirable that landfills be situated in  
11 hydrogeological settings where impacts  
12 due to off-site contaminant migration  
13 will be minimal because the groundwater  
14 is of little or no present or future  
15 value or where the time to first off-  
16 site arrival of contaminants is very  
17 long and the maximum eventual off-site  
18 flux of contaminants is small."

19 Q. It really has two particular  
20 comments and I wanted to ask you about, in particular,  
21 the statement:

22 "It is desirable that landfills be  
23 situated in hydrogeological settings  
24 where impacts due to off-site  
25 contaminant migration will be minimal



1 because the groundwater is of no present  
2 or future value."

3 Stopping there for a moment, do you agree with that or  
4 not?

5 A. Yes, I agree with that statement.

6 Q. How do you relate that to what you  
7 have found with regard to Site F?

8 A. I believe that Site F falls into  
9 that category.

10 Q. With regard to the next phrase  
11 which is really not to do with -- let us ask you if you  
12 agree with the next part of it, to put it in context:

13 "It is desirable that landfills be  
14 situated in hydrogeological settings  
15 where the time to first off-site arrival  
16 of contaminants is very long. The  
17 maximum of eventual off-site flux of  
18 contaminants is small."

19 Do you agree with that?

20 A. I would agree with that as an  
21 alternative to the first part. We have an either/or  
22 here.

23 Q. Dr. Rowe has examined that  
24 particular aspect with regard to Site F?

25 A. Yes, he has, that is correct.



1 Q. Perhaps to avoid not forgetting  
2 about that I will ask Dr. Rowe just to comment, if he  
3 would, on that particular statement with regard to Site  
4 F, the last part of it. Let me show it to you here,  
5 the statement being:

6 "It is desirable that landfills be  
7 situated in hydrogeological settings  
8 where the time to first off-site arrival  
9 of contaminants is very long and the  
10 maximum eventual off-site flux of  
11 contaminants is small. Time is a factor  
12 that should be incorporated into ..."

13 Can you indicate to the Board just in a summary way  
14 what your conclusions are with respect to Site F having  
15 done the work you are going to be telling us about  
16 later on today in the context of that statement?

17 DR. ROWE: A. Mr. Chairman, later today  
18 I will be indicating to you that on the basis of the  
19 information available to me and the analyses I have  
20 performed I have concluded that the impact on  
21 groundwater quality south of the 403 will be minimal  
22 due to a landfill at Site F.

23 Q. Now, the next paragraph in your  
24 witness statement I wanted to take you to is paragraph  
25 79. In a Ministry of the Environment document which



1 was published prior to the Trow studies on Site F being  
2 completed there was a concern raised with respect to  
3 the potential need for a liner at Site F. Could you  
4 give us, please, your opinion as to whether or not a  
5 liner is or is not required?

6 DR. CHARLESWORTH: A. It is my opinion  
7 a liner is not required at Site F. I would draw the  
8 Board's attention to the fact that liners have not been  
9 installed at either Bayview or Burlington.

10 DR. KINGHAM: I wonder if you can  
11 elaborate for the Board on that very point. The  
12 evidence we have heard already is that a percentage of  
13 leachate would be lost under the proposed engineering  
14 design. Are you disputing that conclusion or are you  
15 saying whether it is lost or not it is of no concern?

16 DR. CHARLESWORTH: I am saying whether  
17 it is lost or not it is of no concern. If it is lost  
18 from the refuse which undoubtedly some will be, some  
19 will be collected in the leachate collection system,  
20 obviously a majority of it will, but some will get  
21 through into the groundwater system. If it is not  
22 subsequently picked up by toe drains it will be into  
23 the system I have described and it will not reappear at  
24 the ground surface. I say it is not a problem.

25 DR. KINGHAM: I guess what the Board



1 would like to know at some point in these hearings is  
2 whether you are telling us that, I think it was a five  
3 per cent figure we were given, every day some five per  
4 cent would escape that zone, would escape the immediate  
5 landfill and enter the environment. That five per cent  
6 a day is of no concern to you having left the landfill.

7 DR. CHARLESWORTH: It is of no concern  
8 to me because the only way in which it will leave the  
9 site is in the groundwater system within the shale  
10 which is poor quality water and it will not reappear at  
11 the surface, it will not impact on wells and also the  
12 evidence you will be hearing from Dr. Rowe is that in  
13 any case it will be attenuated by mechanisms that  
14 occur.

15 DR. KINGHAM: I just wanted that  
16 clarification in light of the comment about the liner.

17 MR. ESTRIN: Q. Dr. Rowe, do you want  
18 to add something?

19 DR. ROWE: A. Perhaps I can just add I  
20 will be addressing this in more detail, Dr. Kingham,  
21 whether it is five per cent or less than five per cent  
22 or, secondly, what sort of attenuation one could expect  
23 as that very small percentage of contaminant, potential  
24 contaminant moves laterally through the shale.

25 Q. Actually that brings us to a



1 somewhat related topic perhaps and that is what is the  
2 situation as we can determine it with respect to  
3 whether there was any till or not underneath Burlington  
4 and/or the Bayview Park Landfill Sites at the time  
5 garbage was placed there. You may recall, Mr.  
6 Chairman, that there was an exhibit introduced by  
7 Burlington which was used for the purposes of  
8 attempting to suggest that there was some clay till at  
9 least in some locations underneath the Bayview Park  
10 Landfill.

11 Dr. Charlesworth, have you -- and we are  
12 really therefore looking at paragraph 81 now and 82 of  
13 the witness statement -- have you examined some aerial  
14 photographs with regard to the history and development  
15 of the Bayview and Burlington Landfill Sites?

16 DR. CHARLESWORTH: A. Yes, I have.

17 Q. Do you have these here and could  
18 you bring those out? What is it is we are going to be  
19 seeing, Dr. Charlesworth?

20 A. We are going to be looking at  
21 enlargements of aerial photography for a number of  
22 years dating back to 1934. We have also stereo pairs  
23 of this photography so we were able to examine it in  
24 more detail but we have prepared these enlargements for  
25 the benefit of the Board.



1  
2 MR. ESTRIN: Mr. Chairman, three of  
3 these were obtained from Energy, Mines and Resources in  
4 Ottawa. The other photograph is from the Ministry of  
5 Natural Resources in Toronto. My friends were all  
6 advised that these were available for previous  
7 inspection if they wanted to.

8 DR. KINGHAM: When you say you have  
9 stereo pairs, you have the smaller ...

10 DR. CHARLESWORTH: That is correct.

11 DR. KINGHAM: ... photographs for each  
12 of these exhibits you have?

13 DR. CHARLESWORTH: For each of these  
14 exhibits.

15 DR. KINGHAM: I wonder if these could at  
16 least be entered as exhibits as well.

17 MR. ESTRIN: Yes, we can do that.

18 DR. CHARLESWORTH: We don't have them  
19 with us at this very moment.

20 DR. KINGHAM: At some stage.

21 MR. LANCASTER: Perhaps we could give  
22 them a number and a subsidiary number for the stereo  
23 pairs.

24 MR. HODGSON: I wonder -- I was  
25 suggesting that perhaps he would like to put the device  
for reading them in evidence as well.



1 DR. KINGHAM: It is not always necessary  
2 to have the device to read stereo pairs. I understand.

3 MR. ESTRIN: If the Board wished to look  
4 at the stereo pairs we can certainly make a viewer  
5 available. I believe that the consultants for all the  
6 other parties I am certain have that or we would be  
7 glad to lend ours.

8 Q. First of all, what photographs?  
9 Let us get a number.

10 DR. CHARLESWORTH: A. There is going to  
11 be a series of four enlargements.

12 Q. Perhaps we can give the first one.  
13 What is the date of it?

14 A. This is October, 1934.

15 Q. Perhaps that ought to be given a  
16 number and a letter assigned to the stereo pairs.

17 MR. LANCASTER: That will be Exhibit  
18 M-449 and the stereo pair, M-449A.

19 --- EXHIBIT NO. M-449: Photograph of October, 1934

20 --- EXHIBIT NO. M-449A: Stereo pair of M-449

21 MR. ESTRIN: Q. The next one would be  
22 what year?

23 DR. CHARLESWORTH: A. The next one is  
24 1950, 450?

25 MR. LANCASTER: Four fifty, yes and 450A



1 will be the stereo pair.

2 --- EXHIBIT NO. M-450: Photograph of 1950

3 --- EXHIBIT NO. M-450A: Stereo pair of M-450

4 DR. CHARLESWORTH: 1959.

5 MR. LANCASTER: M-451 and 451A.

6 --- EXHIBIT NO. M-451: Photograph of 1959

7 --- EXHIBIT NO. M-451A: Stereo pair of M-451

8 DR. CHARLESWORTH: And finally 1972.

9 MR. LANCASTER: M-452 and M-452A.

10 --- EXHIBIT NO. M-452: Photograph of 1972

11 --- EXHIBIT NO. M-452A: Stereo pair of M-452

12 MR. ESTRIN: Q. First of all,

13 Dr. Charlesworth, with respect to -- are we finished  
14 numbering them all?

15 DR. CHARLESWORTH: A. Yes, I have.

16 Q. First of all, looking at M-449,  
17 can you just lift up the overlay for a moment? So that  
18 is what it looks like without the overlay. Can you  
19 point out then -- put the overlay down. What does the  
20 overlay have on it, the structural features?

21 A. The overlay has both some features  
22 which were existing at the time and some more recent  
23 features which we have added, obviously approximately  
24 but as accurately as we could get them. So, for  
25 example, the railroad track existed at that time and



1 that is marked on the bottom here. A Bell telephone -  
2 -a Bell line can be seen on the photograph there and we  
3 have also marked that on the overlay. Highway 403 did  
4 not exist at that time but it is approximately in this  
5 location here (indicating). We have also marked on  
6 the locations of -- the present location of the Bayview  
7 Park Landfill, the Burlington Landfill, the 1980  
8 extension and the 1984 extension. Then we have some  
9 lines drawn on here with regard to our interpretation  
10 which I will be referring to in a moment.

11 Q. All right. What significant --  
12 what of significance do we see in Exhibit M-449?

13 A. There are a number of points both  
14 of interest and significance. We see that the area now  
15 occupied by the Bayview Park Landfill that excavation  
16 had taken place at that time. You can, looking at the  
17 stereo photographs more easily than this photograph see  
18 clearly that the cover has been, certainly the  
19 vegetation has been stripped off, the cover has been  
20 stripped off and you can identify exposed rock outcrops  
21 in these areas which we have outlined in red. No  
22 activity of any significant extent was taking place in  
23 Burlington at that time and it is interesting to note  
24 the site of Falcon Creek which was completely treed on  
25 that occasion.



1 Moving down to the area south of the 403  
2 it is interesting to note there was quite an extensive  
3 plant there which apparently was operated by National  
4 Sewer Pipe and it is where they were processing the  
5 clay that they were excavating in these areas. It is  
6 interesting to note a rail spur in here to the plant  
7 which no longer exists. The plant of course no longer  
8 exists and even at that time an abandoned, a couple of  
9 abandoned rail sidings in there.

10 Q. Dr. Charlesworth, you said they  
11 were processing clay. Do you mean they were  
12 processing clay or shale?

13 A. Both. Primarily shale I presume.  
14 It is interesting to look in the area ...

15 Q. You are indicating an area?

16 A. I am indicating an area west of  
17 King Road, south of the existing -- the current 403  
18 north of the railroad track. This is the area  
19 identified by Trow originally as their discharge area.  
20 It is interesting to note that at that time this area  
21 looked significantly different. There is no evidence  
22 of cattails growing in there. There is no evidence of  
23 wetland as such. There is some indication of shallow  
24 water table at some locations but not the wetland even  
25 as we see it now.



1 It is also interesting to note of course  
2 that a large part of this area that I am referring to  
3 north of the railroad track is pasture and south of the  
4 railroad track were orchards, fields and various crops.  
5 There is some evidence, not totally relevant to this,  
6 but there is some evidence moving sort of westward, and  
7 there again I am using the local convention, of some  
8 previous extraction taking place south of where the 403  
9 is now, south of the Burlington Landfill. Again I will  
10 draw your attention to the fact that there was  
11 extensive excavation in the area which is now occupied  
12 by the Bayview Park Landfill.

13 Q. Perhaps we can go now to the next  
14 one which is 1950 in terms of year.

15 A. 1950 is the next photograph.

16 Q. Exhibit M-450. Can you lift up  
17 the overlay for a moment if it is not taped down?

18 A. It is taped down.

19 Q. Again, what are we seeing here?

20 A. We are seeing excavation in the  
21 Bayview Park area, some of the excavation we saw  
22 before. Quite clearly rock exposed in some of these  
23 locations, some stripping and excavation in what is now  
24 Site F. The plant just south of the 403 is now in the  
25 process of being abandoned. I would like to mention,



1 it is interesting to note that that plant was there  
2 back in 1934 because it highlights that this whole area  
3 is not a sort of pristine area. There has been  
4 industrial activity taking place in there and it is  
5 conceivable that that could complicate attempts to  
6 assess pollution and this kind of thing in the area  
7 south of the 403 because there has been activity going  
8 on over the years.

9           You can see the railroad tracks have  
10 been abandoned. The branch line, all the branch lines  
11 have now been abandoned. You can still see there were  
12 tracks going up that brought the material down to the  
13 plant. Extensive excavation in the southern part of  
14 what is now the Burlington Landfill and you can see,  
15 when you look at the excavations and the sides of the  
16 slopes, you can actually see the banding which is the  
17 harder green bands that you get in the shale which we  
18 now observe when you walk around Site F. You won't be  
19 able to see them from where you are sitting but you can  
20 see them on the aerial photography and it makes it  
21 quite clear we are looking at exposed rock.

22           Q.     Dr. Charlesworth, looking at the  
23 area of the Burlington Landfill there appears to be in  
24 the centre portion some areas that are darker than the  
25 obviously lighter areas. Do you have any views as to



1 whether or not some of that is not -- never been  
2 excavated or alternatively did that represent some re-  
3 vegetation?

4 A. It looks like re-vegetation.

5 Q. Can you give us -- I don't know if  
6 you have attempted to do this and if you haven't, you  
7 may not want to do this at this point. It may be  
8 something you want to think about over night, the  
9 percentages of the Burlington site that appears to have  
10 been excavated as of that point.

11 A. I don't have that figure to mind.  
12 I would like to take time to assess that.

13 Q. Now, anything else then  
14 specifically with regard to this exhibit? Again, what  
15 about the discharge area?

16 A. The discharge area?

17 Q. The supposed discharge area.

18 A. The supposed discharge area, it is  
19 not evidence of wetlands as such. Throughout this  
20 area, you can see the area south of the 403, you can  
21 see evidence on all of the photographs of where  
22 excavation had taken place. There would be some water  
23 or some ponding so there is evidence of a shallow water  
24 table in this area but not evidence of a wetland or  
25 discharge zone.



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Q. The next one is Exhibit, what is it, M-451?

A. M-451. This is the 1959 photography and some interesting aspects. This is oriented differently but here again we have marked on Highway 403 and the railroad track. There is evidence here of what we saw in the other photograph, there is evidence here of excavation. You can compare them and see some re-vegetation is occurring.

Q. You are referring to?

A. The Burlington Landfill Site, there has been some evidence of re-vegetation; in the Bayview Park Landfill, actually the first photograph in which we see evidence of refuse appearing on the site. You can see this clearly on the aerial photography that there has been filling at the south end of the Bayview Landfill.

Within the area that had been indicated as a discharge zone we still don't see the sort of wetland-type appearance. There is actually something -- some small excavations there which seem to be -- have some wetness but they don't have the cattails. The plant by now has been abandoned completely and is partially dismantled.

Q. What about the area to the west of



1 the Burlington Landfill where there was some vegetation  
2 in previous years?

3 A. Yes. On the flanks of Falcon  
4 Creek you can see now that the vegetation has been  
5 stripped and there has been removal of material on the  
6 side of the valley there.

7 Q. Dr. Charlesworth, what time of  
8 year is that photograph?

9 A. This photograph is taken in  
10 spring, in April.

11 Q. It will have some relevance to  
12 water table potential?

13 A. Certainly at a time when you would  
14 expect high water tables.

15 Q. All right. The last of these is  
16 Exhibit M-452. The date of that is?

17 A. The summer of 1972. I should say  
18 in the stereo pairs we have a set from -- we haven't  
19 got an enlargement of it -- for 1969. There is -- by  
20 1972 Bayview Park Landfill is pretty well full. There  
21 seems to be some activity taking place towards the  
22 northern end and the Burlington Landfill, we can now  
23 identify landfilling activity taking place in the  
24 southern part of the landfill. The most interesting  
25 thing, this becomes apparent in the 1969 stereo pairs



1 and also if you look at these in stereo, it is the  
2 first time we really start to see this wetland type of  
3 terrain down here. You can see quite clearly on the  
4 1969 photography that there seems to have been some  
5 excavating taking place and moving of earth in this  
6 area. It appears that it is now the area, now appears  
7 like sort of cattail wetland area. It has actually  
8 been excavated slightly. It appears to be at a lower  
9 elevation and I believe that is just a phenomenon of  
10 the shallow water table and we have now lowered the  
11 land surface. They have been carrying out various  
12 excavating and filling activities in this area. I  
13 should have noted, by the way, that Highway 403 in the  
14 meantime has appeared which is a major change to the  
15 area. Virtually all trace of the plant that was here  
16 has disappeared. It is showing some small amounts of  
17 excavation on Site F. I think it is quite significant  
18 that we see a change in the appearance of this  
19 discharge area.

20 Q. This area that has been termed a  
21 discharge area?

22 A. This area that has been termed a  
23 discharge area between the 1959 and 1969 photography.

24 Q. Well, Dr. Charlesworth, having  
25 reviewed those photographs and the stereoscopic pairs,



1 I want to take you back to paragraph 81 of your witness  
2 statement. In it at page 46, it is stated there that  
3 your review will indicate that large portions of the  
4 area of the present Burlington Landfill Site which does  
5 not have an underdrain system is developed on lands  
6 which were apparently mined for clay and for shale and  
7 in any event were stripped of their natural surficial  
8 till cover. Having reviewed all this photography is  
9 that the opinion that you are offering to the Board?

10 A. Yes, that is my opinion. As I  
11 mentioned, you can see quite clearly on these  
12 photographs evidence of the outcropping of the shale on  
13 the areas now occupied by the landfills.

14 Q. Is that statement also true with  
15 respect to Bayview?

16 A. Yes, it is true with respect to  
17 Bayview as well.

18 Q. Now, before we leave the  
19 photographs specifically, in paragraph 82 it is  
20 indicated that you would comment with respect to  
21 whether the southern end of the Burlington Landfill  
22 Site and the Bayview Park Landfill Site were or were  
23 not engineered to current standards as proposed for  
24 Site F.

25 A. In my opinion after looking at the



1 photography and it is not a surprise to anyone, they  
2 were not engineered. You can see, particularly in the  
3 case of Bayview, you can see that they started to dump  
4 into the gullies. Of course at those times landfills  
5 were not engineered in the way that they are today.

6 Q. Now, one more document I wanted  
7 you to comment on with respect to this general topic is  
8 Exhibit B-216. Do you have a copy of that there,  
9 Dr. Charlesworth?

10 A. I do.

11 Q. You will see that this has some  
12 data with respect to test pit and leachate well  
13 locations installed at Bayview Park Landfill Site and  
14 first of all there is a map at page 3 showing the  
15 location of certain monitoring locations. Then we come  
16 to some stratigraphy logs and the first one is LW-1-86  
17 which is in the southwestern corner of the Bayview Park  
18 Site, the map indicates. I wanted to direct your  
19 attention to what we find in these logs below the  
20 refuse. You will see it says cover soil in the log,  
21 then refuse, then clay, clay with silt sand, red. Let  
22 us go to the next hole, LW-2. The same general  
23 description covers soil, refuse, clay with silt sand,  
24 red and then weathered shale. The same in the next one  
25 I believe, cover, refuse, silty clay, red, and then



1 weathered shale. The same in the next one, LW-5, the  
2 same in 6 and my question relates to your opinion as to  
3 whether or not when these logs are stating that they  
4 are describing clay above weathered shale, what your  
5 opinion is of the matter.

6 A. I think it is quite likely -- it  
7 is my opinion that in most cases they are probably  
8 actually recording shale. What I am saying here is  
9 that I think -- I should add first that I haven't tried  
10 to relate these locations as shown on the map actually  
11 to the various photographs and see if we can see  
12 exactly what happened there. Generally we know from  
13 looking at the aerial photography that large parts of  
14 the area were excavated down to the shale and I have  
15 little doubt that that was the case. Also in walking  
16 around the area, just looking at the outcrops not in  
17 the Bayview Park area but in Site F where you can still  
18 see the outcrops of the rock at the side, I think it  
19 would be quite easy and quite understandable -- it is  
20 not a criticism of the logs -- to have difficulty in  
21 distinguishing between shale, weathered shale and the  
22 overburden. I think when you drill through refuse I  
23 think it would be quite possible to think that you were  
24 into what was originally overburden but in fact is  
25 shale.



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Q. Dr. Charlesworth, I don't know if you have it in the room but do you have a photograph of some weathering that you have in fact encountered at one of these sites?

A. You didn't tell me you were going to ask me that one. I think I do have the photographs actually. Yes, I do.

Q. When were these photographs taken?

A. These photographs were taken the 9th of January of this year.

Q. By you or your associate?

A. These particular ones were actually taken by me.

Q. Since, unfortunately, we don't have copies ...

A. I have two copies.

Q. You have two copies or one copy?

A. I have two of a particular view.

Q. If I can hand one to the Board and you can describe it. Perhaps we can have that marked. It is a photograph with a red person in the middle of the photograph, a person dress in red, I should say.

MR. HODGSON: Just before we give that a number, just to unify the exhibits, the witness in giving his evidence on an aerial photograph, 1969, a



1 stereo pair, he gave evidence about a stereo pair and  
2 in the circumstances it seems to me that that '69  
3 stereo pair should also be given a number.

4 MR. ESTRIN: That's fine, we can reserve  
5 a number for that.

6 MR. LANCASTER: I guess we had better  
7 make it 453 then with an A on it so it will indicate it  
8 is a stereo pair.

9 --- EXHIBIT NO. M-453A: Stereo pair of 1969

10 MR. LANCASTER: This photograph will be  
11 M-454 then.

12 --- EXHIBIT NO. M-454: Photograph of January 9, 1988

13 MR. ESTRIN: Q. Dr. Charlesworth, where  
14 is this photograph taken?

15 DR. CHARLESWORTH: A. This photograph  
16 is located in one of the gullies. We were walking  
17 through several of them but in the northern part of  
18 Site F, roughly around the centre of the site.

19 Q. In what direction, generally?

20 A. I think we are looking generally  
21 eastward on that.

22 Q. What is it that you see in the  
23 photograph?

24 A. The thing that struck me about  
25 this when we were out there was that we clearly have



1 shale forming that hillside. It is quite eroded, it is  
2 quite weathered but we know it is shale. You can see  
3 the bands, Mr. Chairman, sort of coming down a couple  
4 of metres from the top of the hill.

5 Q. Hold up the photograph so we can  
6 see what you are pointing to. Hold it so the Board can  
7 see it.

8 A. We have these lighter-coloured  
9 bands which are actually green when you are in the  
10 field which are horizons within the Queenston shale and  
11 the point I am just making on this is that when you  
12 actually go look at this it is quite weathered. It is  
13 very friable and soft. I think if you were augering  
14 through, if you had a significant thickness of other  
15 material on top and you were drilling down and sampled  
16 into that material unless you encountered one of the  
17 green horizons you could very easily believe that you  
18 were in till overburden material rather than in the  
19 shale itself.

20 DR. KINGHAM: What time of day did you  
21 take the picture?

22 DR. CHARLESWORTH: Yes, it was late,  
23 mid-afternoon. You can see there is a fairly long  
24 shadow there.

25 MR. ESTRIN: Q. There appears to be



1 some gully in the picture. Can you talk about that?

2 DR. CHARLESWORTH: A. There is pretty  
3 extensive erosion on the slopes there which is what you  
4 would expect, a large proportion of the precipitation,  
5 obviously the rainfall runs off down those slopes and  
6 erodes the slopes.

7 Q. Now, I would like to return to  
8 your report on Site F and the only part of it we have  
9 not yet discussed in evidence is Chapter 6, the  
10 overview of impact assessment. This is Exhibit M-437  
11 and I am directing your attention, first of all, to  
12 page 6-1 and I am only essentially going to take you to  
13 aspects of this that have not already been discussed in  
14 a detailed way. Would you look at the bottom of page  
15 6-1 and would you read that last paragraph, please, up  
16 to the end of the sentence that continues at the top of  
17 page 6-2?

18 A. "It seems clear that any water  
19 moving to depth beneath Site F or the  
20 Burlington or Bayview Landfills will  
21 move slowly within the regional flow  
22 system towards Hamilton Harbour. As has  
23 been amply demonstrated by the various  
24 studies undertaken in the area, the  
25 water in this deep system is highly



1 saline. This salinity serves as a  
2 tracer in detecting possible discharges  
3 to the surface."

4 Q. Stopping right there:

5 "This salinity serves as a tracer in  
6 detecting possible discharges to the  
7 surface."

8 There has been some evidence or opinions expressed that  
9 because there is so much salinity here it makes this  
10 site virtually impossible to detect anything if  
11 leachate was to get into it. Would you comment on that  
12 with regard to the sentences you have just read?

13 A. Well, yes, it certainly makes it  
14 difficult to detect leachate in the saline water. We  
15 recognize that from the work that other people have  
16 done. However, what the salinity does make easy for us  
17 to do is to determine if that saline water, if this  
18 water from the Queenston shale is reappearing in  
19 springs or seepages because it is so saline that it  
20 would be recognizable.

21 Q. To that extent is there some  
22 positive aspect to the salinity?

23 A. Yes, I see it as a positive  
24 aspect. It is something that enables us to identify  
25 the water from the shale if it reappears at the ground



1 surface or in a shallow groundwater system such as the  
2 fresh water lens that occurs downgradient.

3 Q. In that context would you read the  
4 next sentence?

5 A. "A review of downgradient  
6 conditions between the landfill areas  
7 and Hamilton Harbour has not produced  
8 any indication of the discharge of  
9 saline waters."

10 Q. Stopping there, you mentioned  
11 yesterday and stated here that Trow has taken  
12 measurements of the electrical conductivity too and  
13 your firm has also done that?

14 A. That is true. We found no  
15 evidence of highly saline waters occurring in those  
16 creeks and I would say no evidence of saline waters  
17 occurring in those creeks.

18 Q. Did your work testing for salinity  
19 go from the sites down to the lake?

20 DR. KINGHAM: Could I have that last  
21 question?

22 MR. ESTRIN: Q. Did your work testing  
23 for salinity go from the sites down to the lake?

24 DR. CHARLESWORTH: A. We sampled at a  
25 number of locations down Falcon Creek to cross-check



1 with Trow's measurements on Indian Creek.

2 Q. Now, looking down, if you turn the  
3 page to page 6-3, I am directing your attention to the  
4 third paragraph, beginning:

5 "In our opinion ..."

6 I would like you to read, first of all, that first  
7 sentence.

8 A. "In our opinion the absence of a  
9 viable groundwater resource within the  
10 shale which has been clearly  
11 demonstrated by the work carried out  
12 over the years makes Site F a good  
13 location for a waste disposal site."

14 Q. You then set out a quotation from  
15 a document by Cherry and Lush, 1980, commenting on the  
16 proposal by National Sewer Pipe. Perhaps you had  
17 better read the quote and I want you to comment on it.

18 A. "Based on the low yield capability  
19 and poor quality of the natural  
20 groundwater, it is reasonable to  
21 conclude that the Queenston shale, in  
22 the area that could be affected by a  
23 landfill on the NSPL site or by the  
24 Bayview and Burlington landfills is not  
25 a groundwater reservoir of significant



1 value in the context of regional supply  
2 of potable water or of an industrial  
3 water supply. Even if the relevant cost  
4 of desalting water diminishes greatly in  
5 future decades, it is unlikely that  
6 groundwater in the Queenston shale in  
7 the area of potential leachate influence  
8 will acquire significant value."

9 Q. Stopping there, do you agree with  
10 that statement?

11 A. Yes, I do.

12 Q. Would you read the next one?

13 A. "If the hydrogeological assessment  
14 of the NSPL site were to rest entirely  
15 on the question of potential for  
16 contamination of groundwater resources,  
17 there would be no doubt that the site  
18 would be suitable for a landfill."

19 Q. Overall do you agree with that?

20 A. I agree with that.

21 Q. The next reference is to Keros  
22 Cartwright, a consulting hydrogeologist from Illinois.  
23 Do you know of Dr. Cartwright?

24 A. I don't know him personally but I  
25 know of him as a hydrogeologist.



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papers?

Q. Has he authored papers, academic

A. Yes, he has.

you read it?

Q. And the statement you set out, can

A. "... based on the hydrogeology of  
the site ... it is my opinion that the  
proposed landfill is suitable for  
municipal waste."

Q. Is that your opinion or not?

A. That is my opinion.

paragraph?

Q. Then would you read the next

A. "He went on to state that the  
precise groundwater flowpaths have not  
been defined and that each investigator  
has described the flowpaths in slightly  
different terms. He further stated,  
however, that there was little  
significant difference between the  
descriptions. He concluded his review  
with the following comments:..."

Q. Stopping there:

"... each investigator has described the  
flowpaths in slightly different terms.



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He further stated, however, that there was little significant difference between the descriptions."

How does that comment relate to what you were saying to the Board yesterday about taking into account local complexities versus looking at the overall picture?

A. Yes, I think that statement -- I would agree with that statement. It was obviously written before the Trow work and Trow have attempted to make a more rigorous, detailed classification of the flow statement but I believe I agree with this statement.

Q. Then would you go on to the further and last quotation?

A. "In conclusion, the site appears to be well suited for the disposal of municipal waste. The existence of two sanitary landfills on adjacent land provides a unique opportunity to assess the effects of a landfill in this environment. The old Bayview Landfill is especially instructive, since it has been in existence for a considerable period of time.

Leachate from the Bayview Landfill is



1 traceable only a few tens of metres from  
2 the waste. Some leachate may have  
3 become mixed with the deeper brackish  
4 groundwater; however, they are  
5 indistinguishable from the poor quality  
6 water already present in the aquifer.  
7 There is no indication of extensive  
8 migration of leachate from the old  
9 Bayview Landfill."

10 Q. Stopping there, what is your  
11 opinion with regard to those statements?

12 A. I agree with that statement and I  
13 believe it is still applicable even in the light of  
14 more recent investigations.

15 Q. What about the first paragraph:  
16 "The existence of two sanitary landfills  
17 ... provides a unique opportunity to  
18 assess the effects..."

19 A. Yes, I wholeheartedly agree with  
20 that statement, Mr. Chairman.

21 Q. Then go to the last quotation.

22 A. "Considering the carefully  
23 engineered plans for the proposed  
24 landfill, the new landfill should have  
25 little or no impact on the groundwater



1 in the area around the landfill."  
2

3 Q. He was commenting on an earlier  
4 proposal by NSP. Can you give the Board your views  
5 with regard to the present one?

6 A. I think it is equally applicable  
7 to the present proposal that Trow or the Region have  
8 before us.

9 Q. Would you look at the top of page  
10 6-5 and perhaps tell the Board about that?

11 A. I am stating here that these  
12 opinions are in line with our current thinking and in  
13 fact, given the high degree of engineering, we believe  
14 that this is an excellent location for a landfill site.  
15 Then, as I said yesterday, I believe that the poor  
16 quality of groundwater in this area means that it can  
17 be considered as a good resource for the disposal of  
18 waste.

19 Q. Dr. Charlesworth, could you -- we  
20 have reached essentially -- gone through your report  
21 with regard to Site F. Could you give the Board your  
22 overall conclusions in a summary way with respect to  
23 Site F?

24 A. Mr. Chairman, I believe that the  
25 groundwater regime here, though complex in detail, is  
reasonably simple on a more regional scale.



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Q. Is that one conclusion?

A. That is one conclusion. I believe that Trow's justification for the adjustments to their description of the system in moving from their stratigraphic to their hydrostratigraphic classification is somewhat tenuous. However, in my opinion, this is not important when assessing the suitability of Site F.

Q. The second one?

A. That is the second conclusion. I have a third conclusion. The large body of increasingly sophisticated work which has been carried out on the site over the years has failed to define anything that could be described as a contaminant plume despite the fact that these landfills have been there for many years.

Q. Is that the third?

A. The third conclusion. I have a fourth conclusion that there is no evidence of off-site springs or discharge areas which can be related back to the site area. When water infiltrates on the site it either reappears relatively rapidly within the site itself as mainly seasonable discharges or it moves downgradient within the shale towards the lake.

Q. The fourth conclusion. Stopping



1 right there, you say it either reappears relatively  
2 rapidly in the site as mainly seasonal discharges. Can  
3 you relate that back?

4 A. These are the short, very shallow  
5 flowpaths that I am talking about which will be  
6 intercepted by toe drains or appropriate engineering.

7 I have a fifth conclusion that the area  
8 south of the site is served by municipal water supplies  
9 and is not dependent on groundwater nor is the  
10 groundwater used to any significant extent. Moreover,  
11 such use as might be made of the fresh water lens in  
12 the surficial deposit south of the CN tracks, would not  
13 be threatened by the landfill.

14 My next conclusion is that the  
15 development of the northern part of the site first will  
16 provide some degree of protection to the area of the  
17 south while the effectiveness of the collection and  
18 monitoring systems can be evaluated. I think it's  
19 quite important that the proposal is to start in the  
20 northern part of the site so there is an added safety  
21 factor, an added zone between the area we are working  
22 in and the area downgradient site boundary.

23 Finally, I believe we can take comfort  
24 from the fact that in the event the original Trow model  
25 is in fact an accurate representation of the flow



1 system and that if there should be discharge south of  
2 the 403 then as you will be hearing from Dr. Rowe, his  
3 modelling has shown that there would not be a problem  
4 with leachate contamination.

5 DR. KINGHAM: I'm not quite sure that I  
6 understand your second-last point. I see the words and  
7 I heard the words you have just said, landfilling would  
8 start from the north.

9 DR. CHARLESWORTH: The proposal is to  
10 landfill in the northern part of the site first. I  
11 believe this leaves a buffer here so that while they  
12 are landfilling they will install their leachate  
13 collection system. They will be able to do some  
14 monitoring of the system. Any unexpected problems that  
15 do show up at that time, they have all this buffer zone  
16 in which to recognize the problems and to deal with  
17 them, to come up with any appropriate additional  
18 engineering. They are not working down close to the  
19 site boundary is the point I am trying to make. I  
20 suppose in the very absolutely extreme worst case it  
21 might be decided that the site could not continue to  
22 operate. I am talking about something that could not  
23 be foreseen. It might be the Ministry of the  
24 Environment would say "This is a totally unexpected  
25 phenomenon not seen, obviously" and "Stop operation of



1 the site" and you still have a buffer zone down here  
2 where you could be installing interception, collection  
3 systems, et cetera. I think that is quite important to  
4 start at the north end of the site if you have concerns  
5 at all about this site.

6 MR. ESTRIN: Q. All right, those are  
7 you conclusions, are they?

8 DR. CHARLESWORTH: A. Those are my  
9 conclusions.

10 Q. There is one more matter we can  
11 get into and then perhaps we can have coffee. This is  
12 really a transitional topic between Dr. Charlesworth  
13 and Dr. Rowe. Do you have a couple of overheads?

14 A. Yes, I do.

15 Q. I wanted to ask you to address the  
16 relationship between the linear velocity, the average  
17 linear velocity that you have been talking about in  
18 previous evidence, that is how fast things move in  
19 metres per year that we have been discussing versus  
20 something that Dr. Rowe is going to be talking about,  
21 the Darcy velocity.

22 A. Yes, this is just for  
23 clarification of the Board. Dr. Rowe throughout his  
24 report, throughout his presentation will refer to the  
25 Darcy velocity and this is an expression which is



1 sometimes confusing even for hydrogeologists. I would  
2 say it tends to be more of an engineering expression.  
3 The Darcy velocity can actually be thought of as a  
4 flow per unit cross-sectional area. You are looking  
5 at, for example, one cubic metre/square metre of  
6 aquifer per second, for example, which has as a  
7 velocity one metre per second. You are not actually  
8 talking about a velocity of something moving along  
9 there at one metre per second. So the Darcy velocity  
10 is -- involves quantity.

11 The second slide is just an example to  
12 illustrate the relationship between Darcy velocity and  
13 average linear velocity. I have used extreme values  
14 here just to simplify the matter. I am taking the case  
15 if you assume the pipe, tube or whatever with water  
16 flowing through it and if we assume that that has a  
17 cross-sectional area of a square metre and we assume  
18 that water flows out of there at the rate of one cubic  
19 metre per second, the example I had on the first  
20 overhead, then in one second you would drain a one-  
21 metre length of that pipe. This is an empty pipe --  
22 not an empty pipe but a total cross-sectional area of  
23 one metre. A particle of water, a molecule that was  
24 back there one metre into the pipe would take one  
25 second to come out. So the average linear velocity



1 would be one metre per second which in this case would  
2 be the same as the Darcy velocity.

3 In the second example if we imagine a  
4 case where it was filled with sand, it is a bit  
5 unlikely but if the pore space was half the cross-  
6 sectional area and the solid particles of sand, the  
7 solid grains were half, the other half, so we would  
8 have a void space of half a square centimetre. Then we  
9 would be draining two metres of pipe length. So, if we  
10 had a Darcy velocity of one metre per second, so if one  
11 cubic metre of water in a second came out of there we  
12 would drain two metres of this pipe. So we would have  
13 an average linear velocity of two metres per second,  
14 although the Darcy velocity is still one metre per  
15 second.

16 Then in the third case where it is  
17 filled with sand where the particles made up 90 per  
18 cent of the cross-sectional area and the pores between  
19 were only ten per cent, this is like an effective  
20 porosity of 0.1. So the cross-sectional area that the  
21 water is in is just 0.1 square metres. In that case to  
22 get a cubic metre out of the pipe in a second or a  
23 piece of aquifer would be -- you would be draining a  
24 ten-metre-long length of pipe. So one metre per second  
25 Darcy velocity in this case would have an average



1 linear velocity of ten metres per second. I have just  
2 made a note at the bottom that the Darcy velocity is  
3 also known as specific discharge.

4 MR. ESTRIN: I have copies of those  
5 overheads for the Board which could be marked.

6 MR. LANCASTER: The "Relation of Darcy  
7 Velocity and Average Linear Velocity" is Exhibit M-455.

8 MR. HODGSON: I wonder, Mr. Chairman,  
9 they strike me as one exhibit. Could they just be  
10 stapled together as M-455? I'm just thinking of the  
11 fact we are now storing these things behind tabs or in  
12 file folders. It seems a shame to separate them.

13 MR. LANCASTER: All right.

14 DR. KINGHAM: A very clear lesson in  
15 this subject. You should be a teacher.

16 --- EXHIBIT NO. M-455: Series of overheads entitled  
17 "Relation of Darcy Velocity  
18 and Average Linear Velocity"

19 MR. ESTRIN: Thank you,  
20 Dr. Charlesworth, I am sure we will be hearing from  
21 you later on but, Mr. Chairman, this would be an  
22 appropriate time to take the coffee break and then we  
23 will be hearing from Dr. Rowe with regard to Site F.

24 MR. LANCASTER: Fifteen minutes.

25 --- Recess

MR. LANCASTER: Please be seated.



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MR. ESTRIN: Q. Dr. Rowe, you are on the spot. Everyone I think is waiting with some anticipation as to how you can attempt to explain the work which you did which is obviously, apparently when you look at it in your report, filled with formulae and various numbers. Therefore, I think they are looking forward to this with some anticipation. Certainly I am.

First of all ...

MR. LANCASTER: Are you going to learn something at this point, Mr. Estrin?

MR. ESTRIN: I hope so.

MR. HODGSON: You will notice he used the phrase "attempt to explain."

DR. ROWE: I will do my very best.

MR. ESTRIN: Q. Dr. Rowe, first of all, to set some context to the detailed work that you did, can we refer, first of all, to your olive-covered report, Exhibit M-440 and I wanted to draw your attention to really the introductory section and in particular to the third paragraph on the first page of this exhibit and to just give us a bit of background there perhaps you could read that paragraph, the third paragraph.

DR. ROWE: A. Certainly.



1 "The phenomenon of attenuation due to  
2 matrix diffusion is well recognized and  
3 was considered in the UWO study."

4 That is the study described in this report:

5 "Thus, the study involved modelling of  
6 contaminant migration along fractures  
7 (due to advective-diffusive-dispersive  
8 transport) together with diffusion of  
9 contaminant from the fractures and into  
10 the matrix of the rock. Possible  
11 sorption of contaminant was also  
12 considered where appropriate. The model  
13 satisfies conservation of mass  
14 requirements. It also automatically  
15 allows for variation in the  
16 concentration in the source leachate as  
17 the mass of contaminant within the  
18 landfill decreases due to both the  
19 collection of leachate and the movement  
20 of leachate down into the rock."

21 Q. We have already come across  
22 certain terms in there which you will be explaining in  
23 greater detail.

24 A. That is correct.

25 Q. I wonder if you could turn the



1 page and look towards the middle of page 2. There is a  
2 sentence that begins over on the right-hand side:

3 "Fortunately, however, the Burlington  
4 and Bayview Park ..."

5 Could you just start with that?

6 A. "Fortunately, however, the  
7 Burlington and Bayview Park Landfills  
8 provide an indication of the movement  
9 (or lack of movement) of contaminant in  
10 an hydrogeologic environment which is  
11 similar to that beneath the proposed  
12 Halton Landfill at Site F. In this  
13 situation, theoretical models can be  
14 particularly useful for examining the  
15 implications of different combinations  
16 of parameters and the choice of  
17 parameters can be tested by comparing  
18 the calculated and observed extent of  
19 migration from existing landfills. By  
20 using these parameters in an analysis of  
21 the proposed Halton Landfill at Site F,  
22 it is then possible to form an  
23 engineering opinion as to the likely  
24 performance of the proposed landfill."

25 Q. Then, perhaps to put your work at



1 those sites in context you could read the last  
2 paragraph on that page.

3 A. Certainly:

4 "From the standpoint of modelling  
5 contaminant migration, the proposed Site  
6 D is at least as complex as Site F and  
7 there is uncertainty regarding the value  
8 of relevant parameters at both sites.  
9 In both cases, modelling using  
10 reasonable combinations of parameters  
11 will provide an indication of the  
12 potential contamination of groundwater.  
13 At Site F there is the unique advantage  
14 of having the documented performance of  
15 the two existing landfills which can be  
16 used to calibrate the choice of  
17 parameters."

18 Q. All right, thank you. One more  
19 page I would like you to turn to, page 12, some  
20 references there to the phenomenon of attenuation due  
21 to the matrix. Would you read the first full paragraph  
22 there without giving us all the references necessarily?

23 A. I think the references are of  
24 importance but I will skip them for you.

25 Q. I don't mean -- skip the dates.



1

A. "The phenomenon of attenuation due  
to matrix diffusion is well recognized."

2

3

There I list quite a lengthy number of references;

4

Barker and Foster, Freeze and Cherry, Grisak and

5

Pickens, Grisak, et al, Sudicky and Frind, Tang:

6

"THCL also recognize the importance of

7

matrix diffusion and discuss this

8

mechanism (pages 86 to 88, Volume 1)

9

using a diagram from Freeze and Cherry

10

to illustrate the concept."

11

And I will in fact be using that diagram in my

12

presentation:

13

"However, in their evaluation of

14

contaminant migration, THCL adopt a

15

simple theoretical model, the Ogata-

16

Banks equation which cannot take

17

account of attenuation due to matrix

18

diffusion. Since a primary objective of

19

the UWO study was to examine the effect

20

of matrix diffusion on potential

21

contaminant migration at Site F, this

22

mechanism will be discussed in a little

23

more detail ..."

24

Q. You are going to be doing that in

25

just a minute. One more reference I believe at page 16



1 at the bottom and the top of 17 on the same point.

2 A. "Foster (1975) showed that the  
3 diffusion of tritium from flowing  
4 groundwater in the fractures of porous  
5 chalk, (i.e. into the pore water of the  
6 porous rock matrix) could account for a  
7 rapid decrease in the tritium  
8 concentration in the fractures.  
9 Similarly Gillam and Cherry reported  
10 that Day used the diffusion to the  
11 matrix concept to account for a rapid  
12 decline in tritium concentration with  
13 depth in a fractured clay in the  
14 Winnipeg area. Finally Grisak, et al,  
15 have also demonstrated that diffusion to  
16 the matrix model can give relatively  
17 good agreement between theoretical  
18 simulations and laboratory experiments  
19 in which a tracer solution was passed  
20 through a large column of fractured  
21 clayey glacial till. From these studies  
22 Gillam and Cherry in their paper  
23 concluded that '... molecular diffusion  
24 can exert a major influence on the rates  
25 and patterns of migration of



1 contaminants in fractured argillaceous  
2 deposits. Diffusive loss of  
3 contaminants from paths of active flow  
4 in the fractures to the matrix can be a  
5 dominant mechanism of attenuation."

6 Q. So prior to your work at Site F  
7 and taking into account matrix diffusion other people  
8 have certainly addressed this concept?

9 A. They have indeed.

10 Q. Why did you feel it important to  
11 consider the role of matrix diffusion with regard to  
12 Site F?

13 A. Having reviewed the documents on  
14 Site F I felt that matrix diffusion would be an  
15 important mechanism in showing the attenuation of  
16 contaminants from both the existing site and the  
17 proposed site.

18 Q. I wonder if we could turn to  
19 outline for the Board the scenarios to which you  
20 applied the concept before we start to understand the  
21 concept itself, just the situations, the assumptions or  
22 the scenarios you were working.

23 A. Perhaps if I can start with  
24 an overhead and, Mr. Chairman, I am going to be working  
25 from a number of overheads which are in general



1 reproduced for you in the witness statement which is  
2 Exhibit M-444 and the overheads are contained, for the  
3 most part, under tab 2. I am beginning with No. 5.

4 Now, there are a number of  
5 possible interpretations of the hydrogeology at Site F.  
6 You have heard at some length of THCL's or Trow's  
7 interpretation. You have also heard from  
8 Dr. Charlesworth as to his interpretation. In terms of  
9 my modelling I have considered both. Just to put the  
10 situation in perspective I have shown here a sketch  
11 indicating Trow's better-fit type model. This is going  
12 to be what I refer to as scenario C in my witness  
13 statement. Basically if one reads Trow's reports they  
14 have something they refer to as a weakly-fractured  
15 shale which in the better-fit model they say has a  
16 vertical hydraulic conductivity at  $10^{-8}$ . If one looks  
17 through the report they typically indicate that this  
18 zone might be in the order of 15 to 20 metres thick.  
19 They also have a so-called highly fractured shale which  
20 in their better-fit model has a horizontal hydraulic  
21 conductivity of  $10^{-4}$ . Based on the data it is  
22 reasonable to expect that if their idea is right this  
23 highly-fractured shale is more than five metres and of  
24 the order of five to ten-metres thick. If one adds  
25 these two things up we are looking at a zone where in



1 Trow's view the majority of the flow is occurring which  
2 is between 20, 15 + 5 gives the minimum thickness to 30  
3 metres thick. In fact I will discuss modelling that I  
4 did using the flow from Trow's model towards the end of  
5 my discussion on Site F. So, I will come back to this  
6 particular scenario.

7  
8 For the next while I would like to talk  
9 about the scenario proposed by Dr. Charlesworth. This  
10 is a simpler scenario that doesn't have these neatly  
11 defined units. It has a general fractured shale unit  
12 and this unit, if one looks at the data, might be  
13 typically 20 to 30-metres thick. Dr. Charlesworth  
14 mentioned a figure of 25 metres in his evidence. In my  
15 scenario A I looked at the situation where contaminant  
16 could move straight down into the fractured rock  
17 without any problems and I was concerned with the  
18 attenuation as contaminant migrated laterally  
19 downgradient of the landfill. So, I was concerned with  
20 attenuation after or I was concerned with modelling the  
21 movement of contaminant after it got to the toe here  
22 which is a very conservative situation.

23 My scenario B is a slight modification  
24 of this scenario and I will discuss it in more detail  
25 when I come to it.

Q. Dr. Rowe, for the Board's



1 assistance if they were to turn to paragraph 6 of your  
2 witness statement there are the three scenarios that  
3 are set out there I believe in a summary form.

4 A. That is correct.

5 Q. Just to ...

6 A. Paragraph 6 on page 4.

7 Q. If you look at paragraph 6,  
8 scenario A is you said the scenario developed from  
9 Dr. Charlesworth?

10 A. That is correct, scenario A is  
11 based on Dr. Charlesworth's hydrogeologic  
12 interpretation. It is the scenario dealt with in my  
13 Site F report.

14 Q. All right. Then B, scenario B is  
15 a variation of A and you will discuss that later?

16 A. That is correct.

17 Q. Scenario C relates to -- roughly  
18 corresponds to Trow's better-fit model?

19 A. It was an attempt by me to get  
20 some idea of what contaminant transport might occur if  
21 one accepts their better-fit model.

22 Q. Originally you did your -- and in  
23 your Site F report you told us is related to scenario  
24 A. I take it from a point of view of time you didn't do  
25 the modelling with regard to Trow's better-fit until



1 obviously you heard about it, it was September?  
2

3 A. I think the better-fit model  
4 arrived in September.

5 Q. Fine. Please proceed.

6 A. There is one other point I would  
7 like to add, Mr. Chairman, that when I look at the  
8 idealization or the interpretation of the hydrogeology  
9 from Dr. Charlesworth he mentioned to you that he  
10 indicated a hydraulic conductivity of  $4.5 \times 10^{-6}$  cm/s.  
11 I used that hydraulic conductivity and the gradient  
12 given to me by Dr. Charlesworth. I looked at higher  
13 hydraulic conductivities. For example, if one takes  
14 the same gradient, I will be indicating in my evidence  
15 that I looked at what is equivalent to a hydraulic  
16 conductivity of  $1.1 \times 10^{-5}$  and  $6.3 \times 10^{-5}$  when I tried  
17 to understand what might be happening at the Burlington  
18 Landfill. So, I will be discussing that as I move  
19 through my evidence.

20 Q. Now then, we come to the concept  
21 of matrix diffusion.

22 A. That is right. We are talking  
23 about matrix diffusion so I think it is perhaps good to  
24 start by indicating what we mean by the matrix. On  
25 this schematic here I have attempted to indicate a  
fracture shown here with matrix of the rock, the shale



1 on either side of it. The shale is not one solid  
2 block. It has voids in it or pores as we refer to it.  
3 In a saturated rock those voids or pores are filled  
4 with water. So we have a lot of pores or voids within  
5 the rock itself plus we have the fractures.

6 Now, the notation that I am going to use  
7 through my evidence is that the width of the fracture  
8 is  $2b$  and the spacing or the width of a solid block of  
9 material between fractures is  $2h$ . So the spacing  
10 between fractures is  $2h$ . As I say there are two levels  
11 of voids or I think in his evidence Dr. Charlesworth  
12 referred to primary and secondary permeability. That  
13 is the same thing as what I am talking about here. The  
14 voids in the fractures, these fractures are very, very  
15 small. If you look at the information available it  
16 suggests that the fractures are typically less than 500  
17 microns. Five hundred microns is half a millimetre.  
18 So we are talking about fractures that are typically of  
19 the order of the thickness of one's fingernail. It is  
20 a very, very small fracture on the whole. This is a  
21 very small distance and the amount of space in those  
22 voids is very small. So a typical fracture porosity,  
23 that is the amount of space in the voids compared to  
24 the total mass of material is, as Dr. Charlesworth  
25 indicated, something like 0.001.



1                   The voids in the matrix is another  
2 matter. Within the rock itself we have lots of holes.  
3 Now, Trow in their report indicate a value of about 0.1  
4 for the porosity. That is about ten per cent of the  
5 rock, the shale itself, is space or voids filled with  
6 water. I will indicate later that our own tests would  
7 support this general number.

8                   Porosity is defined as the volume of  
9 voids divided by the total volume. What this means is  
10 that if we look at a general mass of rock and the  
11 matrix porosity is about 0.1 and the fracture porosity  
12 is 0.001 then 99 per cent of the water in that rock is  
13 in the pores of the rock matrix itself. Ninety-nine  
14 per cent is in the pores of the rock itself and only a  
15 very small proportion, the order of one per cent is  
16 actually in the fractures.

17                  Now, we are dealing here with saturated  
18 rock so all of this has water in it. When contaminant  
19 enters the system what happens is we have contaminant  
20 dissolved within the water. The leachate consists of  
21 chemical species such as chloride or benzene or other  
22 contaminants dissolved in the water. As these  
23 chemicals move along a fracture they are going to tend  
24 to move into the matrix of the rock, into the water.  
25 This is particularly true of things that are not



1 already there. You have heard evidence that chloride  
2 is in the rock in high concentrations. I will come  
3 back to that. Let us suppose at this stage that we  
4 have something like benzene which is not naturally  
5 occurring in the rock in significant concentrations.  
6 Let us suppose that some of that benzene enters one of  
7 these fractures. As it enters the fractures it is at  
8 a higher concentration than the concentration in the  
9 pore fluid of the rock. So by process of matrix  
10 diffusion, which I will explain in a moment, that  
11 contaminant is going to move out of the fracture into  
12 the water which represents 99 per cent of the water in  
13 the system, based on those numbers. That is the  
14 attenuation mechanism which I am going to be dealing  
15 with.

16 DR. KINGHAM: Before you remove that  
17 overhead, your fracture planes could as easily be  
18 vertical, diagonal, any direction?

19 DR. ROWE: That is correct.

20 DR. KINGHAM: Did you assume that the  
21 fracture frame thicknesses were uniform throughout?

22 DR. ROWE: In terms of the modelling I  
23 did but I will address that question in some more  
24 detail for you.

25 MR. ESTRIN: Q. Now, at one point in



1 the earlier testimony Ms Vigod put a question or a  
2 suggestion to Mr. Feenstra that appeared to imply from  
3 the question that sand could absorb leachate but rock  
4 couldn't. Can you comment on that in perspective of  
5 the rock such as shale at Site F?

6 DR. ROWE: A. I think that analogy was  
7 a totally inappropriate analogy and has nothing to do  
8 with what is going on at Site F. Here what we are  
9 concerned about is contaminant moving through the  
10 fractures and into the open space within the rock.  
11 This has nothing to do with having a pool of water on  
12 the ground and sprinkling sand on it or tossing a hunk  
13 of rock on it. They are totally different mechanisms  
14 involved.

15 Q. Now, would you proceed to talk  
16 about the next aspect of this particular phenomenon?

17 A. Yes. I have alluded to diffusion  
18 in the matrix but I haven't really told you what it is  
19 all about and that is what I am going to attempt to do  
20 in the next short while.

21 We have heard from Mr. Sobanski and  
22 Mr. Feenstra that they believe that matrix diffusion  
23 occurs but there has been the suggestion that it is  
24 complicated or it is hard to understand, that there is  
25 uncertainty regarding parameters such as fracture



1 spacing, et cetera. I would agree that there is  
2 uncertainty regarding parameters such as fracture  
3 spacing, fracture opening size. What I would like to  
4 do is try and address those questions in two ways. In  
5 my Site F report I address the effect of these  
6 uncertainties using a fairly rigorous mathematically  
7 oriented theoretical model. I will be coming up to  
8 explain the figures and the rationale.

9  
10 I thought it might be of assistance to  
11 the Board if I tried to explain the concepts in terms  
12 of an analogy first then we can come to the detailed  
13 results. I have got here a definition of diffusion  
14 which is a fairly standard definition. For the  
15 purposes of my analogy I would like to, for the next  
16 number of overheads, have you picture a group of people  
17 flying over long distance, for argument's sake from  
18 Toronto to Sydney. These people have to land somewhere  
19 in the Middle East because of an engine failure in the  
20 plane. So we have 200 people loaded into a holding  
21 bay. Let us suppose for the sake of argument they  
22 arrive somewhere around 6:00 o'clock at night and they  
23 are kept in this small holding bay for six hours. Then  
24 they are told, "Okay, it's going to take us another  
25 three hours to fix the engine. You can go anywhere you  
like within this building but be back here in three



1 hours." Because it is the middle of the night and  
2 nothing opened, the one thing they want to do is get  
3 away from other people. That is all there is for them  
4 to do. Now, this is a very crude analogy, something  
5 like what is happening in diffusion. We have a whole  
6 lot of people together and they are sick of being  
7 together and they would like to have more space. When  
8 you have a lot of people together it is a concentration  
9 of people. Concentration is by definition mass per  
10 unit volume. In terms of my analogy it would be the  
11 number of people per square unit area, people per  
12 square metre, say. If you have a lot of people crowded  
13 together in a holding bay and a small door leading out  
14 into a large area, when they go through that door they  
15 are going to spread out to get away from other people.  
16 This is the same thing that is happening with molecular  
17 diffusion. If you have a lot of molecules close  
18 together in a very crude sense it's like a lot of balls  
19 bouncing against each other. As they hit each other,  
20 they tend to move away from where there is a lot of  
21 balls to an area where there are fewer balls. So, this  
22 is moving from high concentration to low concentration.  
23 This is what we are going to be talking about,  
24 contaminants coming down fractures where they are at  
25 high concentration and moving into the matrix of the



1 rock where they are at lower concentrations. So, in  
2 summary then, diffusion involves the movement of  
3 contaminant from the fractures, if it is at high  
4 concentration in the fractures, in the fractures, to  
5 the pore water within the rock itself where the  
6 concentration or if the concentration is lower there.  
7 So that is one important concept that I am going to be  
8 using.

9 Another concept was raised by  
10 Dr. Charlesworth. He mentioned two velocities and very  
11 clearly defined Darcy velocity which is related to a  
12 flow and he defined the average linear velocity. In  
13 fact in many books this is called the average linear  
14 groundwater velocity which he has abbreviated here to  
15 average linear velocity and which I will abbreviate to  
16 groundwater velocity. We are talking about the same  
17 thing. It is just to say average linear groundwater  
18 velocity every time becomes a little bit repetitive.

19 So, we have two velocities. I am afraid  
20 I am going to introduce a third; that is the velocity  
21 or speed at which contaminant moves. So, Darcy  
22 velocity is related to the flow of water, how much  
23 water is moving. The average linear groundwater  
24 velocity is related to how fast a water molecule is  
25 moving. The contaminant velocity is related to how



1 fast the contaminant itself is moving. What I am going  
2 to demonstrate to you is that it is not always the same  
3 as the groundwater velocity.  
4

5 Q. In the concepts that you are  
6 going to be talking about, Dr. Rowe, can you tell the  
7 Board whether or not the concepts are the same or  
8 similar to concepts Mr. Feenstra utilized at some  
9 points of his work?

10 A. Yes, I think that is an important  
11 issue to address.

12 Mr. Feenstra in his modelling which is  
13 in his own report as well as in Trow's report at Site  
14 F, modelled diffusion of contaminant, advective  
15 diffusion transport of contaminant down through this  
16 weakly-fractured shale.

17 MR. HODGSON: Mr. Chairman, this is the  
18 second or third time this has happened. The witness  
19 has very carefully numbered each one of his overheads.  
20 I wonder if he could be asked, through you, that when  
21 he goes from one overhead to another that he can  
22 indicate for the purposes of the transcript what  
23 overhead he is addressing so we can also allude to it  
24 when reading the transcript later.

25 DR. ROWE: I would be pleased to do  
that, Mr. Chairman. I am referring, I am sorry, to



1 overhead No. 5.

2 DR. KINGHAM: Just so that we know, all  
3 of the overheads you are going to be referring to are  
4 reproduced in your exhibit at some point or do we need  
5 them as exhibits themselves?

6 MR. ESTRIN: I think the answer is  
7 essentially most of them are in the book and have a  
8 number. Where they are not in the book we can make  
9 those separate exhibits.

10 MR. LANCASTER: Is this the same one you  
11 referred to, No. 5 before?

12 DR. ROWE: I referred to No. 5 before in  
13 setting the scenarios and now I am going to respond to  
14 Mr. Estrin's question about the concept of matrix  
15 diffusion where the concepts that I am using are the  
16 same concepts that Mr. Feenstra has already used  
17 because Mr. Feenstra, it wasn't the better-fit model,  
18 he did his work before the better-fit model was  
19 developed. He modelled on the original Trow flows,  
20 advective diffusive transport down through this weakly-  
21 fractured shale. It is exactly the same mechanism as I  
22 am talking about except that my diffusion is occurring  
23 from the fractures into exactly the same shale. It  
24 should be the same diffusion coefficients. You should  
25 be getting exactly the same level of sorption of



1 reactive contaminants such as benzene. So exactly the  
2 same basic concept of diffusion as Mr. Feenstra has  
3 already talked about. The difference is that he had it  
4 all diffusing down through this zone and when I said  
5 "diffusing", that was one of the mechanisms he looked  
6 at whereas I am looking at diffusing from the fractures  
7 into the matrix itself. It is the same physical  
8 concept of diffusion.

9 MR. ESTRIN: Q. The same physical  
10 concept he used but applying it to different aspects of  
11 the rock?

12 DR. ROWE: A. That is correct.

13 I would now like to refer to Figure No.  
14 9 in the list of transparencies and I have some  
15 conclusions there which I will come back to. For the  
16 time being I will push them slightly off the screen.  
17 We don't have as much space as one would hope here. I  
18 am going to try and explain how the velocity or speed  
19 at which contaminant moves may or may not be -- may or  
20 may not be the same as the groundwater velocity. I am  
21 going to start with the simplest case, that is the case  
22 where there is no matrix diffusion.

23 For the purposes of my example I am  
24 going to assume in terms of calculation that we have a  
25 Darcy velocity of one unit. I am going to look at a



1 fracture which is one unit wide initially. If we  
2 consider the total spacing,  $2h$ , between fractures to be  
3 ten then our fracture porosity will be one divided by  
4 ten which is 0.1. So, as Dr. Charlesworth explained,  
5 the average linearized groundwater velocity would be  
6 equal to the Darcy velocity divided by 0.1, so  
7 therefore ten. We are going to deal first of all with  
8 the left-hand side of this diagram.  
9

10 I am going to explain it in the context  
11 of my people in their holding bay. For the purpose of  
12 argument, let us suppose there are 200 people confined  
13 in this holding bay which has an area of 40 square  
14 units. So that means there are going to be five people  
15 per square unit before the doors are opened. Out of  
16 that holding bay we have a corridor which has a moving  
17 walkway on it as they have in many airports. The speed  
18 at which that walkway moves is analogous to the  
19 groundwater velocity. If somebody just stands on it  
20 and keeps moving with that conveyor belt it is like  
21 moving at the groundwater velocity. If people were to  
22 try and walk on that conveyor belt, we have often  
23 experienced at airports, we have some people who stand  
24 and some people who are in a hurry who try to work  
25 their way between the people standing on it. That  
process of people walking on the conveyor belt trying



1 to dodge other people is rather like dispersion. We  
2 have heard in previous testimony about mechanical  
3 dispersion. Now, in my detailed evidence I will  
4 discuss that but for the purposes of this simple  
5 illustration let us suppose that people don't want to  
6 walk on the conveyor themselves, so they are standing  
7 and moving along with the speed of the conveyor.

8 Now, let us suppose that in some time,  
9 delta t, 0.2 units, ten people move out that door and  
10 jump on the conveyor belt. I have marked the people  
11 right out front. I have put a dab of red paint on  
12 their coats so we can see what happens to them. So  
13 they stepped on the conveyor belt and in the unit of  
14 time, delta t, the distance they will move is equal to  
15 the groundwater velocity multiplied by the time. So  
16 it is going to be ten units times 0.2 moves a distance  
17 of two units. If we just leave those people standing  
18 on the conveyor belt at two units of time it is fairly  
19 obvious they will have moved twice as far. In three  
20 units of time they will now have used six units. So  
21 this is a case where if we regard these people as  
22 contaminants, I am not meaning to infer anything nasty,  
23 these contaminants would be moving at the same speed as  
24 the conveyor belt. That is to say they are essentially  
25 moving at the same speed as the groundwater velocity.



1 Now, let us ask ourselves what happens  
2 if the corridor was only half as wide. This is  
3 completely analogous to saying, "Well, what happens if  
4 we reduce the fracture spacing by two?" So on the  
5 right-hand side of the picture I have the same 200  
6 people initially locked up in this room. This time the  
7 conveyor belt is only half a unit wide which means that  
8 instead of people being able to stand side by side,  
9 only one person between the walls of the corridor. If  
10 I am going to get the same ten people out of the  
11 holding bay in a unit of time, then clearly this  
12 conveyor belt has to work twice as hard. It has to  
13 travel twice as fast. So we can see to get the same  
14 number of people moving out in the same period of time  
15 this conveyor is moving twice as fast or in terms of  
16 the groundwater, the groundwater velocity instead of  
17 being ten units is 20 units. We have the same Darcy  
18 velocity but divided here by a porosity which is 0.05.  
19 That gives us 20 units.

20 So in the same period of time the guy  
21 with the red paint on his back has moved a distance of  
22 four units instead of two units. In three units of  
23 time he will have moved a distance of 12 units. So  
24 this illustrates something that is well recognized;  
25 that is if you have a system with no pores in it, if



1 this were crystalline rock, no pores at all, no matrix  
2 diffusion could occur then the speed at which  
3 contaminant would move would be the same as the  
4 groundwater velocity neglecting dispersion. So that is  
5 the first concept and you can see here that in this  
6 case, and this case only, changing the porosity doubles  
7 the speed at which the contaminant moves. I am going  
8 to demonstrate to you that when you consider matrix  
9 porosity that no longer holds.

10                   The other thing I would like to draw  
11 your attention to, Mr. Chairman, from this overhead is  
12 the concept of decreasing concentration with time.  
13 Here are 200 people locked in a holding bay. The area  
14 of the holding bay remains constant but the number of  
15 people in that holding bay gets smaller as some of them  
16 move out. So, originally we had 200 people in an area  
17 of 40 units, so that is five people per square unit.  
18 At this time here ten of them have moved out. So we  
19 now have 200 minus ten, that is 190 people in the same  
20 40 square units. So we have dropped down to 4.75 and I  
21 have rounded that to 4.8. As more people move out the  
22 concentration in our holding bay in this case drops.  
23 Of course this same thing happens in a landfill. When  
24 you close the landfill up there is a finite amount of  
25 mass within that landfill. There is a finite amount of



1 benzene, there is a finite amount of any of the  
2 contaminants you are talking about. As they are  
3 removed either by the leachate collection system or  
4 possibly by movement down into the underlying rock in  
5 this case, the concentration in the landfill will be  
6 reduced because you have got fresh water coming in from  
7 infiltration but the mass of contaminant coming out.  
8 It is exactly the same idea as we have here, volume  
9 remaining more or less constant but the number of  
10 people or the mass of contaminant moving on.

11 Q. Now, at one point in his testimony  
12 Mr. Feenstra stated that the degree of attenuation  
13 depended very, very significantly on the actual rate of  
14 groundwater flow through the cracks, the aperture or  
15 opening size of the cracks, the effect of the diffusion  
16 coefficient. Are you going to address each of those  
17 aspects?

18 A. I will indeed.

19 Q. In summary, what will you be  
20 concluding with regard to those?

21 A. I am going to demonstrate to you,  
22 Mr. Chairman, that it is not the groundwater velocity  
23 that is important. What is most important is the Darcy  
24 velocity; that is how much stuff is moving. Not how  
25 fast the water is moving but what is the total mass



1 loading on the system, what is the total amount of  
2 fluid flowing through the rock, that is the important  
3 thing. What I am going to show you or attempt to show  
4 you, first by analogy and subsequently by detailed  
5 results is that in fact the matrix porosity has very  
6 little effect on the contaminant migration. Of course,  
7 the groundwater velocity is equal to the Darcy velocity  
8 divided by the matrix porosity. So if you change the  
9 matrix porosity by a factor of ten your groundwater  
10 velocity goes up by a factor of ten. What I am saying  
11 is that if you have the same total flow to the system  
12 it is not important. It doesn't matter if you don't  
13 know what that porosity is by a factor of ten. What is  
14 important is the total loading on the system, not the  
15 speed at which an individual water molecule is moving.

16 Q. Thank you.

17 A. I am now referring to schematic  
18 No. 10 in the witness statement which is a schematic  
19 showing matrix diffusion. A moment ago we looked at  
20 the extreme case where there was no matrix diffusion,  
21 if you like where the diffusion coefficient into the  
22 matrix was zero. To illustrate the concept I am now  
23 going to go to the other extreme. Let us assume it is  
24 infinite matrix diffusion coefficient; in other words,  
25 it doesn't take significant time for contaminant to



1 move into the pores of the rock once it gets to a  
2 point. Then of course in my detailed evidence I will  
3 show you what the effect of varying that number is  
4 within the range of zero to infinity which are  
5 obviously ridiculous bounds. The concept I think is  
6 clearly appreciated if we look at these two extremes.  
7 This is our same holding bay but now we have a number  
8 of corridors or spaces off the side of this moving  
9 walkway. These might be other smaller holding bays.  
10 This is analogous to the pores within the matrix.  
11 Obviously I cannot draw this to the scale we have in  
12 rock because in rock the thickness of these corridors  
13 is in microns or hundreds of microns. The spacing  
14 between the fractures is five to ten to 30 centimetres.  
15 The distances we are talking about laterally can be  
16 hundreds of metres. So one can appreciate that really  
17 I can't draw the thing precisely to scale or even close  
18 to scale. What is important is that there is an awful  
19 lot of matrix, there is an awful lot of water in that  
20 matrix, 99 per cent based on those numbers I gave you.  
21 That means most of the space available for contaminant,  
22 for people to go to get away from other people is in  
23 the matrix in our little bays off. So as you see, I am  
24 going to add bays but here is a whole lot of separate  
25 spaces off the side of the corridor, off the side of



1 our moving walkway.

2 I am going to try and lead you through  
3 this. Let us suppose that originally we had our 200  
4 people sitting in the holding bay and they are told  
5 that they can go and do what they like until the plane  
6 is fixed. So naturally, having been through this one  
7 appreciates it very well, you want to get away from all  
8 these people. The one thing in your mind is to get  
9 some space. Now, suppose that ten of these people move  
10 out through the door, as many as can move out in one  
11 unit of time. Some of them are going to notice this  
12 corridor here and they are going to move down this  
13 corridor because that is a way of getting space. By  
14 assuming an infinite diffusion coefficient I am just  
15 saying that they can move down here very quickly. It  
16 doesn't take time to move from this point to this  
17 point. That is a simplification but not a major  
18 simplification as we will see.

19 Now, I would like to take one person to  
20 begin with and put a daub of red paint on him. Here is  
21 the poor devil who looked up here and saw it starting  
22 to get pretty crowded so I am not going to move in  
23 there. He is the leading guy on the conveyor belt. He  
24 was probably the eighth guy out of the holding bay.  
25 The first seven or eight of them popped up here. He



1 decided it was already getting too crowded. He would  
2 stay on the conveyor belt and find a better space to  
3 rest. So, in the next unit of time he comes along and  
4 finds another holding bay so he moves up to get himself  
5 some space. That is where he is going to stay until  
6 the plane is fixed.

7  
8 Now, of course there is another guy who  
9 has just come out of the holding bay and in this unit  
10 of time, he was previously in the holding bay and I  
11 have noted him in green here. Previously in the  
12 holding bay but now he has moved out so after two units  
13 of time he is sitting down at the end of this  
14 particular holding bay, the pore. It is getting pretty  
15 crowded there so he decides he is going to stay on the  
16 conveyor belt until the third unit of time he comes  
17 past this holding bay. It is pretty uncrowded, it has  
18 only got the red dot in it when he first arrives,  
19 perhaps one other guy, so that is a good place to go.  
20 He moves up into that zone. Of course one can keep  
21 going with this. There is another fellow in blue here  
22 who comes past, he sees this getting a bit crowded so  
23 he moves along and pops up into this holding bay. We  
24 can follow this whole procedure along. You can see  
25 that the man in red is still sitting there. The man in  
green is still sitting there. Once they get into the



1 pores of the rock, once they get into the holding bay  
2 they are going to stay there until something convinces  
3 them there is a good reason to move. In the case of  
4 our analogy the plane is fixed.

5 If we follow this through, we can  
6 actually follow the dots and this is an arithmetic  
7 exercise. I actually tried to follow each of these  
8 dots using simple arithmetic, there is nothing more  
9 complicated here than simple arithmetic. After ten  
10 units of time what we find is that people as they come  
11 out of this holding bay have been spreading into these  
12 corridors to reduce the concentration, to get away from  
13 people. Because of the amount of space that is there  
14 in the holding bays or in our case Site F within the  
15 pores of the rock, after ten units of time the guy who  
16 is still sitting on the elevator or the moving walkway  
17 is at that point. He is a marker of how far  
18 contaminant has moved and where we can detect  
19 contaminant in the fracture. There might in fact be a  
20 tiny amount of contaminant that moved past that point  
21 and into the pore that we can't see in the fracture.  
22 He is the guy who marks where the contaminant is on our  
23 moving walkway, in our groundwater. In that ten units  
24 of time he has only moved this distance here. Yet, in  
25 that same period of time if we put a blob of paint on



1 the moving walkway, the walkway has travelled this  
2 distance (indicating) so that the groundwater has moved  
3 this distance but the contaminant has only moved this  
4 distance because of this desire to get out of this very  
5 thin corridor, thin fractures into this large amount of  
6 water, relatively speaking, in the matrix of the rock  
7 or in our holding bays here. All the time contaminant  
8 is being driven from high concentration to low  
9 concentration. That is the overriding principle. It  
10 is always going to go from where there are more people  
11 to where there are less.

12 So what this is demonstrating is that  
13 when one considers matrix diffusion contaminants do not  
14 move at the same speed as the groundwater. In fact,  
15 matrix diffusion substantially reduces the speed of  
16 contaminant movement along the fractures.

17 There is something else I would like to  
18 draw to your attention in this overhead. I spoke with  
19 respect to the last overhead, that is overhead No. 9,  
20 about the finite mass of contaminant, in this case the  
21 finite number of people in the holding bay and how the  
22 concentration will decrease as people move out. We  
23 started out with five, we get 4.8, 4.5, 4.3. As time  
24 goes on, until after ten units of time there are only  
25 three people per unit of area in our holding bay. As



1 people move out on to the conveyor belt, initially they  
2 move out at a concentration of five people per unit  
3 area. Of course, when they zip down into this holding  
4 bay we have a lot more space for the people. They can  
5 spread out. So, in this case here we have one person  
6 per unit area, obviously a big step up from five. Then  
7 another bunch of people come out, they were originally  
8 at 4.8 people per unit area, they get out here and they  
9 see all this space. When they first arrive there is  
10 only one person per unit area. That is a whole lot  
11 better than 4.8 people per unit area so they spread  
12 out. Of course, that increases the number of people.  
13 It is not so good for the ones who are already there  
14 but it is better for the ones moving in because they  
15 are going from 4.8 people per unit area to what now  
16 becomes 1.8 people. So, the concentration in this pore  
17 is increasing. You can see that after three units of  
18 time it has gone up to 2.3, 2.7, 2.9. If we move on to  
19 the next time, because the concentration here is 3.9,  
20 the people coming out into the corridor are now 3.9  
21 people per unit area. Three point nine comes out, he  
22 sees "Well, there are three people there. That is  
23 better than 3.9. It is still worth my while" for some  
24 of them to move into this. So we get going from 2.9 to  
25 three, 3.2, 3.3, 3.4, 3.4. What we see here is that



1 there is a point beyond which it is not worth moving  
2 into this first pore. We can see by the time ten units  
3 have gone by, the concentration in the holding bay is  
4 three people. So, now we have three people per unit  
5 area coming out but because of the time lag this is now  
6 at 3.4. There is no motivation for people to move into  
7 this. They are going to keep moving on. Instead there  
8 is now motivation for people to move out of this  
9 corridor and so we can get diffusion back out of the  
10 pore once the concentration peak is passed. In fact in  
11 this case here you can see the concentration peak in  
12 this first pore is going to be about 3.4 units. That  
13 is the maximum concentration that is going to occur at  
14 that point. Here we see a glance of attenuation.  
15 Remember when we were back in the holding bay the  
16 maximum was five. By the time we have moved to the  
17 first pore space the maximum is going to be about 3.4.  
18 That is the highest it is going to get and if we were  
19 to follow this on at later times, we would eventually  
20 find people spreading out as far as they can and the  
21 concentration dropping.

22 So, the second point I would draw to  
23 your attention is just from this simple analogy one can  
24 see that the maximum concentration in a fracture is  
25 less than the original source concentration. The



1 concentration is going to decrease with distance away  
2 from the source. In this case the distance away from  
3 the holding bay. In the real situation, of course, the  
4 distance away from the landfill. As the contaminant  
5 spreads out into all of this pore space, this 99 per  
6 cent of the parameters I looked at in my earlier slide,  
7 the concentration is going to be reduced. You have got  
8 the same number of people spread over a larger area.  
9 That is what we are talking about with attenuation of  
10 conservative contaminants. This happens even for  
11 contaminants which do not interact with the rock.

12 Now, of course, if there is an  
13 interaction then there will be more attenuation and I  
14 will come to that. This process of matrix diffusion  
15 will work even for conservative species and results in  
16 a reduction of concentration with distance away from  
17 the source or from the landfill.

18 Q. Now, I believe you are now going  
19 to take us to -- to discuss one of the points  
20 Mr. Feenstra mentioned, the effect of any fracture  
21 porosity.

22 A. Yes, I will. This is moving to  
23 schematic No. 11 in the witness statement. It is a  
24 schematic showing that if one considers matrix  
25 diffusion then fracture porosity has a minimal effect



1 on the speed at which contaminants move along a  
2 fracture. On my left-hand side of this diagram we see  
3 essentially the same figure that we looked at a short  
4 while ago on the previous slide No. 10. I have just  
5 reproduced here in essence the results we looked at a  
6 moment ago, assuming a fracture width of one unit. As  
7 we saw, the distance a contaminant moved was much  
8 smaller than the distance groundwater moved in the same  
9 period of time. What I would now like to explore is  
10 what would happen if the fracture were only half as  
11 thick. So let us take a fracture thickness of 0.5  
12 units. To maintain the same Darcy velocity, to  
13 maintain the same flow through the system, it follows  
14 that the groundwater velocity has to double; that is to  
15 say to get the same number of people out of this  
16 holding bay in the same period of time the conveyor  
17 itself has to move twice as fast. So, if we were to  
18 put a lot of green paint on the conveyor, that green  
19 paint on the conveyor is moving twice as fast. We are  
20 not concerned about how fast the water moves. That is  
21 not important. What is important is how fast the  
22 contaminant moves.

23 We have ten people moving out of the  
24 holding bay in both cases. There are lots and lots of  
25 pores in this rock and this distance is, relatively



1 speaking, a large distance compared to the fracture  
2 space. So that when ten people move out on the  
3 conveyor belt in this case, as soon as they see this  
4 first fracture they all zip down. Most of them zip  
5 down it in the first period of time to minimize the  
6 concentration. In this case here the conveyor belt  
7 will move twice as far in the same period of time so  
8 there are more fractures available, but nevertheless  
9 people will move down these available bays, so the  
10 concentration will be reduced. There are two people  
11 who make the decision that there is no advantage for  
12 them to move into these holding bays. The reason there  
13 is no advantage is they want to keep the concentration  
14 or the amount of people per unit space as low as  
15 possible. So these two red people stay on the conveyor  
16 belt after the time  $\Delta t$ . After two units of time  
17 the conveyor belt has now moved to this position. It  
18 is shown by the arrow on the second part of the  
19 diagram. The people see two more areas which are  
20 unoccupied. So, they move into those areas. Now,  
21 there are another two people which I have marked in  
22 blue here who are on the conveyor belt at these  
23 locations at time  $2 \Delta t$ . In the next unit of time  
24 the conveyor belt moves to here (indicating), yet  
25 these people are moving no more than the speed of the



1 conveyor belt so they come along and see all of this  
2 space so they move into the pores. So after four units  
3 of time we can note the person at the head of the crowd  
4 coming out and still on the conveyor belt, he is the  
5 man in green here. If we look at how far he has moved  
6 just by the simple arithmetic process, just arguing  
7 that when people see space they move into it, we see  
8 that he has moved in essence the same distance as if  
9 the porosity were twice that value. So the contaminant  
10 -- the guy in green who is the leading person standing  
11 on the conveyor belt has still only moved this distance  
12 despite the fact the conveyor belt has moved to here.  
13 So the groundwater has moved twice as far but to all  
14 practical purposes the leading person or contaminant  
15 has moved the same distance. It may not be precisely  
16 the same but to all practical purposes.

17 So, this is an analogy which only uses  
18 arithmetic which attempts to demonstrate what one can  
19 show with the more rigorous mathematical formulation;  
20 that is that decreasing the fracture porosity by a  
21 factor of two, or as I will show later even orders of  
22 magnitude, does not significantly change the location  
23 of the contaminant front or the speed at which the  
24 contaminant migrates. It is because the contaminant is  
25 trying to get into all of this pore fluid within the



1 rock. There is little incentive for it to stay in  
2 these tiny fractures and be carried by the water.

3 Q. Now, perhaps if your voice is  
4 holding up we can try one more schematic before we  
5 break for lunch.

6 A. I think this is certainly an  
7 appropriate one to show before lunch. I am referring  
8 now to schematic No. 12 which is a schematic showing  
9 the effect of matrix diffusion coefficient. In fact  
10 there is nothing new about this overhead because what I  
11 have done is drawn together parts of several of the  
12 previous overheads. On the left-hand side you can see  
13 the situation where no matrix diffusion has occurred.  
14 So, I have drawn the holding bays but there is some  
15 barrier that stops people moving into those holding  
16 bays. That is equivalent to assuming zero diffusion  
17 into the matrix. If we look at the concentrations of  
18 contaminant within that fracture, initially there were  
19 five people per unit area. When they hop on the  
20 conveyor belt because there is nowhere else for them to  
21 go there are still five people per unit area. There  
22 are going to be five people per unit area moving along  
23 at the front of the conveyor belt. So, at this point  
24 in time here there would be five people per unit area  
25 on the conveyor belt at that location. That five moves



1 from there to there to there (indicating). Because  
2 five people have moved out of the holding bay, we now  
3 only have 4.8 and so we are going to be reducing the  
4 concentration, moving out with time. So the  
5 concentration is going to drop within the holding bay  
6 but the peak concentration within the fracture is going  
7 to be five. The precise value of these numbers is not  
8 relevant. What is important is that no matrix  
9 diffusion means that the peak concentration at any  
10 point downgradient is going to be equal to the peak in  
11 the landfill neglecting dispersion. When we consider  
12 matrix diffusion we have a completely different  
13 situation. Again, these are results that I have shown  
14 before assuming an infinite diffusion coefficient. You  
15 can see that the concentration on the conveyor belt is  
16 related to how much space is available for the  
17 contaminant to move in to it.

18 As I indicated before the concentration  
19 will increase. For example, at this location it will  
20 increase with time. At this point in time at three  
21 units it is 2.3. I showed before that it might move up  
22 to somewhere about 3.4 before it peaks out and then  
23 decreases again. The important point here is that when  
24 we consider matrix diffusion we have attenuation. The  
25 peak concentration at this point will be less than it



1 was at this point. As we move further away from the  
2 source, the peak concentration will get smaller and  
3 smaller. That is the process of attenuation.

4 We can conclude from all of the work  
5 that I have done but one can infer it from the results  
6 shown here, that zero matrix diffusion coefficient  
7 gives the maximum concentration in the fractures. An  
8 infinite matrix diffusion coefficient gives the minimum  
9 concentration in the fractures. The truth will lie  
10 somewhere in between. The point I would like to drive  
11 home here is that it is conservative, that is to say it  
12 is a worst case to consider a diffusion coefficient in  
13 the matrix smaller than what you really think it is in  
14 the field. So that if I had some laboratory data which  
15 said one value and for design calculations I use a  
16 smaller value, it will give me higher concentrations in  
17 the fractures. It is a worst case to use the diffusion  
18 coefficient to less than what you really think it is.  
19 As you will see, Mr. Chairman, that is what I did in my  
20 modelling.

21 Q. Perhaps we might, just before the  
22 break, go to the illustration of matrix diffusion from  
23 Cherry and Freeze.

24 A. I am going to refer now to  
25 overhead No. 13 which is a reproduction from my report



1 which was a reproduction from Trow's report which was  
2 of course a reproduction from Freeze and Cherry. It  
3 has travelled some distance and lost some clarity on  
4 the way. This is the basic concept that Trow discussed  
5 in their report and it is quite in agreement with  
6 everything that I have told you. I have simply tried  
7 to elaborate that if one had no matrix diffusion and an  
8 infinite source of contaminant then you would get what  
9 we often call flood flow moving along something like  
10 this (indicating). If there is a bit of dispersion  
11 then that will smooth this curve off somewhat but for  
12 the sake of argument let us not worry too much about  
13 that.

14 If we consider matrix diffusion what  
15 happens is that contaminant is moving from the fracture  
16 into the pores of the rock. In my example a moment ago  
17 I assumed infinite diffusion coefficient. Of course it  
18 is not infinite, it does take time for the contaminant  
19 to move into this rock. So if we were to trace the  
20 contaminant front it might look, at least  
21 schematically, something like this (indicating). Up  
22 near the front contaminant has two advantages; it has  
23 had a longer time to move and also a higher  
24 concentration driving. So therefore it has moved  
25 further up here than some point down here. So, this is



1 in yellow showing where the contaminant might be in the  
2 rock, in the matrix of the rock. This is plotting how  
3 the concentration might look assuming an infinite  
4 amount of contaminant in the fracture itself. Because  
5 mass is being removed from the fracture, moving into  
6 the matrix of the rock, there is a decrease in  
7 concentration with distance. That is what you would  
8 expect for a conservative species. That is a species  
9 of contaminant that does not interact with the rock in  
10 any way.

11 Mr. Feenstra and I think Mr. Sobanski,  
12 if I recall, commented on contaminants which interact  
13 with soil or rock. For example, organic contaminants  
14 such as benzene would interact with the organic matter  
15 in the clay, it would tend to partition around the  
16 organic matter. That is an additional attenuation  
17 mechanism. That is what is illustrated in this lower  
18 portion if we have absorption and not only is  
19 contaminant being removed from the fractures by moving  
20 into the pores of the rock but it is also being removed  
21 from the pore water within the rock. In the case of an  
22 organic it might be attaching itself or trying to get  
23 around the organic matter in that rock. In the case of  
24 something like potassium, say, it might be attaching  
25 itself to the clay-type particles or trying to get



1 closer to the clay particles within that shale. So  
2 there is additional attenuation for contaminants that  
3 react with the material. So, this will limit how far  
4 it moves into the rock in a given period of time and it  
5 will also reduce the concentration with distance away  
6 from the landfill. This is in fact an unrealistic  
7 situation in the sense that these diagrams assume an  
8 infinite amount of contaminant. I will be talking this  
9 afternoon about the importance of modelling the finite  
10 mass. This is a very worst case situation.

11 MR. ESTRIN: Perhaps, Mr. Chairman, we  
12 could break now. This would I think be an appropriate  
13 point and we will come back and finish off a couple  
14 more overheads, the concept and then begin to talk  
15 about what happens at Site F.

16 MR. LANCASTER: We can practice  
17 diffusion now. A quarter to 2:00. Thank you.

18 --- Luncheon recess at 12:27 p.m.  
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1 --- Upon commencing at 1:45 p.m.

2 MR. LANCASTER: Please be seated.

3 MR. ESTRIN: Q. All right, Dr. Rowe, we  
4 are all appropriately spaced in our various matrices  
5 here. Would you go ahead and continue, please, I think  
6 perhaps coming to a diagram, that we might find it as  
7 No. 14?

8 DR. ROWE: A. That is correct.

9 Q. Of the overheads in tab 2 of the  
10 witness statement.

11 A. Figure 14 which shows -- is a  
12 schematic showing the effect of fracture spacing.

13 Mr. Chairman, before the break I was  
14 working through some simple analogues if you like  
15 trying to explain the concept of matrix diffusion. In  
16 that simple analogue I looked at the extreme case of  
17 zero diffusion into the matrix and infinite diffusion  
18 into the matrix. All of that time the only contaminant  
19 in the model I have been using along the fracture, the  
20 only transport mechanism along the fracture I have been  
21 considering is movement with the groundwater. I have  
22 excluded diffusion and dispersion along the fracture  
23 itself. In my detailed modelling I considered that but  
24 to consider it right now would complicate the issue.

25 I would like to carry that a little bit  
further and now try to illustrate to you, again in a  
conceptual way, the effect of fracture space. To do



1  
2 this I need to move to an intermediate case where I  
3 consider that it actually does take time for a  
4 contaminant to move into the pores of the rock which is  
5 indeed the true situation.

6 On this figure 14 you can see that there  
7 is an upper and lower part. Looking firstly at the  
8 upper part I have tried to depict here three fractures.

9 So, you have water coming in from the left-hand side  
10 into these three fractures. The fractures have a  
11 width, each one of one unit and the spacing between the  
12 fractures is  $2h$ . The bottom portion of the diagram  
13 shows exactly the same total distance but only two  
14 fractures. I have increased the fracture width so that  
15 in fact the fracture porosity in both these cases is  
16 the same. All we are looking at is the effect of  
17 having three fractures and therefore a shorter distance  
18 between the fractures themselves as compared to two  
19 fractures and a larger distance between them.

20 I want to try in a conceptual way to  
21 address what might be the implications of fracture  
22 spacing. We will start with the upper portion where we  
23 have the three fractures. I am assuming here that we  
24 have an input of, if you want to put it in terms of our  
25 airport analogy we have got the three different  
conveyors and we have a total number of 18 people



1  
2 entering over this width. So, when we have three such  
3 conveyors there are six people entering each one of  
4 these per unit of time. You will see that there are a  
5 number of little sketches shown. Each of these  
6 correspond to different times. I have marked in orange  
7 here exactly the same position and space. So this is a  
8 reference point, this is where we enter the system.  
9 Let us consider that six people move into the system  
10 and are moving along the corridor and then they find  
11 openings which is pore space within the rock. They are  
12 initially at a concentration which is relatively high,  
13 six people per unit area. Then when they find this  
14 open space, for the sake of argument, two of them move  
15 up a short distance here where the distance that they  
16 move in a unit time is related to the diffusion  
17 coefficient in the matrix. So, how quickly they can  
18 move in this direction is related to the diffusion  
19 coefficient.

20 So, for the sake of argument, let us  
21 suppose that two of them move this way, two of them  
22 stay in the channel and two move this way. A similar  
23 situation will arise at each of these fractures. I  
24 have marked a couple of people, if you like,  
25 contaminants at each junction so we can trace them  
through and see what happens to them.



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Here is the second unit of time, time has advanced and these two were people who originally were at this position, having moved along the conveyor belt, having moved with the groundwater velocity to this location. There is nothing very exciting about that but in the next time step they come to another pore. At this point one of them moves that way because that is where there is some open space and the other moves this way. Likewise, from this fracture we have got people moving out.

If we move on another time step and I am just tracing these two individuals, this individual here, I may perhaps just circle him so that we can follow where he goes. Originally he was just at the beginning of the fracture, just at the beginning of the pore. In the next time step he has moved down some distance into the pore so he is moving away from this fracture into the matrix of the rock. Of course, there is another fracture here so our friend in red at that point has also moved in. So they are moving towards each other from the different fractures.

If we move on another time step then eventually and in this case already they have met. Once they meet obviously they are not going to travel in the opposite direction so there is some point



1  
2 between the two where no longer will the contaminant  
3 move any further into the pores because it is meeting a  
4 contaminant coming from the other fracture. Of course,  
5 while these two people have been followed through the  
6 system, there has been more contaminant coming in. So  
7 originally if we were to look at this part in this pore  
8 there was no contaminant down here but because of the  
9 additional contaminant coming in and moving down we can  
10 see that there is a buildup in concentration within the  
11 pores. That is the situation that we have with our  
12 three fractures. That is the sort of thing we looked  
13 at before we took the break.

14 What I would like to illustrate is the  
15 consequence of having a different fracture spacing. In  
16 this lower slide we have got exactly the same number of  
17 people, namely 18 people entering the system over this  
18 width here in a given time interval. However, we have  
19 only two fractures and they are somewhat wider  
20 fractures. So we have the same concentration, the same  
21 number of people per unit area but we have nine of them  
22 up here and nine of them down here. I have tagged  
23 three of these individuals to try and follow what might  
24 happen to them. So we had nine come in here and let us  
25 suppose, for the sake of argument, a couple pop up and  
get lost out of our story. A couple drop down into



1  
2 this fracture and we are going to tag these three guys  
3 who move on the conveyor belt so that in the next time  
4 interval this is where they are. The time interval  
5 after that they reach a pore space in the rock. One of  
6 them decides to go up and out of the story. One of  
7 them is going to stay on the conveyor belt and one of  
8 them moves down into the matrix. Of course the bottom  
9 fracture where we are having symmetry here there is  
10 another person doing the same.

11 Moving on one more time interval, if we  
12 look at this individual who entered the pore at that  
13 time, given another unit of time he has moved down. He  
14 has moved a distance related to the diffusion  
15 coefficient. If we look at another step in time that  
16 same individual has moved down even further. If we  
17 look at this you can see that at this particular time  
18 with the closer fracture spacing these two red people  
19 have met, so that you can I hope appreciate that if you  
20 have closer fracture spacing you are likely to get the  
21 diffusion coming from the two faces meeting sooner or  
22 the pore space saturating with contaminant at an  
23 earlier time. These ones have not yet met, although if  
24 we advance the solution further forward in time,  
25 eventually they will meet. We can see that if we now  
just look at what is happening within this matrix pore



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2 around here or these matrix pores, we can see at the  
3 first time interval there is a couple of people  
4 entering. Then as time goes on, here they are already  
5 meeting, there is some time before they meet. They  
6 haven't met in this case. Here they have all met. You  
7 have got contaminant coming from this fracture has met  
8 contaminant coming from this fracture. It occurred at  
9 this time interval with a close spacing and at a later  
10 time when we have a wider spacing. So spacing is going  
11 to be related to a time scale. There is going to be a  
12 time scale on this problem affected by the diffusion  
13 coefficient and spacing.

14           The first conclusion I would like to  
15 draw from this slide is that the smaller fracture  
16 spacing reduces the distance the contaminant front has  
17 to travel in a given time. We can see that if we look  
18 at the concentration at this position, for example.  
19 With three fractures, by the time we get to six units  
20 of time, there is still no contaminant reached that  
21 particular point but when we have three -- sorry -- two  
22 fracture spacings, we do have contaminant at that  
23 point. In fact if I was to express it in terms of  
24 number of people per unit area, at this time we have  
25 zero here but we have two at this point. So the wider  
the fracture spacing, the further the contaminant is



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2 going to travel in a given period of time. Especially  
3 on time scales where contaminant is still trying to  
4 saturate the matrix. That time scale is going to be  
5 important as we proceed.

6 DR. KINGHAM: Just a minor point. Are  
7 we talking about the same overall porosity here of ten  
8 per cent?

9 DR. ROWE: A similar sort of porosity.  
10 Obviously I haven't tried to draw this precisely to  
11 scale.

12 DR. KINGHAM: From the perspective of  
13 conservation of mass if you are putting the same amount  
14 in at one end, you have the same amount of available  
15 space, then the overall concentration at the end of  
16 unit time should be the same. Your numbers don't quite  
17 add up in concentration. I just wondered why.

18 DR. ROWE: If we have the same porosity  
19 and you have exactly the same mass in the system, then  
20 obviously you have conservation of mass through it.  
21 That doesn't mean the concentrations will all be the  
22 same at different points through the system. Have I  
23 responded to your question or not?

24 DR. KINGHAM: You have but -- well, I  
25 will let you carry on with this example.

DR. ROWE: Perhaps if there is something



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I haven't explained by the end, please ...

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So, the point I was trying to make here is that if we have closer fracture spacing, at least on small-time scales, then we will get further advancement of the contaminant front, if you like, for the wider fracture spacing than we get with the closer fracture spacing.

Now, I am again going to refer to this slide but I have made another overhead because I have too many things drawn on one picture. I am referring again to overhead 14. This time I am focusing on the concentrations and the point I am going to try and make is that the smaller fracture spacing may give a higher concentration in the fracture than a wider fracture spacing. To illustrate my point I am going to be focusing attention on this first location. So shortly after the contaminant enters the system we can see that at the small spacing between the fractures, if we look at the concentration, that is the number of people per unit area here and I have rounded these numbers. In some cases they should be expressed as a decimal but I have rounded them off. We can see that the concentration increases with time. Initially we have a concentration of six coming in. The concentration at this point here after the first unit of time is two.



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2 It increases to four at this location, this time and  
3 then it is staying at four. I think I have circled the  
4 point I didn't mean to circle in one of these cases.  
5 So we start off here at two. If we look at this  
6 particular point and I apologize, I have circled where  
7 I didn't intend to. There we have two at this  
8 particular time, it is still two at this particular  
9 time, but it increases to four at that time, increasing  
10 to four and because I am doing this in discrete numbers  
11 it is not a smooth curve. My models of the details  
12 are much smoother than this. If we have a constant six  
13 coming in then we are sure everything will always  
14 become six. If we are going to carry this on far  
15 enough and I have an infinite source of contaminant,  
16 then eventually everything will become six. In reality  
17 of course that is not the case. You have a finite  
18 amount of mass and therefore the concentration in your  
19 source will drop. The point I would like to make is  
20 that if we compare what is happening at this location  
21 in these two examples, with the closest spacing we have  
22 a higher concentration slightly than we have with the  
23 wider spacing. So what we are seeing is that the  
24 contaminant is moving faster along the fractures with  
25 the wider spacing but the concentrations may be a  
little bit less at some locations, particularly back



1  
2 from where the front is. So that fracture spacing can  
3 have an effect at small times. The definition of  
4 "small" is related to how long it takes for contaminant  
5 to diffuse right through the matrix and saturate the  
6 matrix. My point here is that at smaller fracture  
7 spacings we may have a higher concentration in the  
8 fracture than at wider fracture spacings when we are  
9 dealing with small time.

10 I am staying on this same overhead,  
11 still 14 but the third point I would like to make is  
12 that after there has been sufficient time for  
13 contaminant to fully diffuse into the rock pores,  
14 fracture spacing ceases to have a significant effect on  
15 the concentration in the fracture. Again we can follow  
16 what happens to people as they move through the system.  
17 For the purposes of illustration, let us look or focus  
18 our attention on this first set of pores. I have  
19 tagged two people entering the pore at this time, 2  
20  $\Delta t$ , two this way and so on. Similarly I have  
21 tagged two people entering this fracture, this pore.  
22 You can see that after one step in time the first  
23 couple I have marked in a purple colour here have moved  
24 down and at this fracture spacing they are already  
25 meeting people coming from the other fracture.  
Whereas, at the wider fracture spacing they are still



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2 quite some distance to go before they meet somebody  
3 coming in another direction. Nevertheless, when we  
4 move on another time step you can see it starting to  
5 get crowded in this fracture. In this fracture they  
6 still haven't met, the purple have moved down but they  
7 still haven't met the purple people coming from the  
8 other direction. Eventually they will.

9                   Moving on to this time step you can see  
10 they have now met and now it is starting to accumulate  
11 in this fracture. So there is a time scale related to  
12 the diffusion coefficient and the spacing between the  
13 fractures. The spacing of the fractures may be  
14 important at short times because in one case the  
15 fractures may be saturated, may have saturated the  
16 pores. In the other case the fractures may be  
17 sufficiently far apart that the pores are not  
18 saturated. If one looks at a time scale which is large  
19 compared to the time it takes for contaminant to move  
20 from one fracture to the centre position between  
21 fractures, then fracture spacing ceases to be  
22 important. So on larger time scales fracture spacing  
23 will not be important. On shorter time scales it may  
24 be important. We are going to see that when I go  
25 through my specific results.

MR. ESTRIN: Q. You will be then



1  
2 putting the terms shorter and longer time into a  
3 specific time context for us?

4 DR. ROWE: A. I will.

5 Q. Now, what is the next overhead?

6 A. The next schematic is schematic  
7 No. 15 showing a three-dimensional fracture system.  
8 Dr. Kingham asked a question earlier about the nature  
9 of the fracture system that one might have in reality  
10 and what it is that I modelled. I would now like to  
11 try and address that issue. In reality one would  
12 expect three-dimensional fractures. You would expect  
13 horizontal fractures and the evidence that would seem  
14 to suggest that they will predominate. Nevertheless  
15 there is likely to be some vertical fracturing. That  
16 can be in two planes relative to the direction of flow.  
17 We can have vertical fractures parallel to the flow  
18 direction so we are assuming flow is travelling in this  
19 direction. We could have vertical fractures  
20 perpendicular to the flow direction.

21 The fracture spacing that I am primarily  
22 modelling is the horizontal fracture spacing which  
23 appears to be the most important. I would like to talk  
24 just a little bit about the consequences of there being  
25 truly a three-dimensional system vis-a-vis what I am  
modelling which is a set of plane or parallel



1  
2 fractures. So this brings us or will bring us in a  
3 moment to schematic 16 and subsequently schematic 17.  
4 Schematic 16 is a section perpendicular to the flow  
5 direction so I am taking a section through this three-  
6 dimensional picture perpendicular to the flow  
7 direction.

8                   Schematic 16 is a schematic showing 2d  
9 and a 1d idealization perpendicular to the flow  
10 direction. So if you can picture flow more or less  
11 passing into the page, here are our horizontal  
12 fractures which predominate and here are some vertical  
13 fractures. Obviously if we have a situation like this  
14 water can be flowing down either of these fracture  
15 parts. When it diffuses into the matrix is therefore  
16 has a possibility of diffusing into the matrix, in this  
17 case vertically upwards from the horizontal fractures  
18 or laterally from the vertical fractures. If we have  
19 the same porosity as these two systems, in other words  
20 if we select the porosity of our one-dimensional system  
21 such that it is equivalent to the real two-dimensional  
22 case, then the effect of diffusion from two directions  
23 means that you can saturate the pores a little faster.  
24 If it was a square box, if the fractures in the  
25 vertical direction were equal to the fractures in the  
horizontal, then that would be essentially the worst



1  
2 case because you could have it travelling as fast in  
3 this direction as in this direction (indicating).

4 Now, the reality of the situation based  
5 on the information I have seen is that the vertical  
6 fractures are somewhat wider spaced than the horizontal  
7 fractures. In any event, what the two-dimensional  
8 versus the one-dimensional system will do is allow the  
9 matrix of the rock to saturate faster. It allows  
10 contaminant to diffuse into the matrix faster and it  
11 will be manifest as if the fracture spacing were  
12 closer. So, if I try to simulate what is happening  
13 here in a two-dimensional situation using a one-  
14 dimensional model then I would get the same type of  
15 behaviour if I simply decreased the spacing so the  
16 effective distance contaminant has to move is smaller.  
17 That takes account of the fact it can come in this way  
18 and this way.

19 The point is that if we can see the  
20 fracture spacing is not a critical issue, then it  
21 doesn't really matter whether it is coming in simply in  
22 a vertical direction from horizontal fractures or  
23 coming in horizontally as well. It will affect the  
24 time scale slightly but providing fracture spacing is  
25 not an issue then whether these fractures are  
horizontal or vertical will also not be an issue. So



1  
2 the conclusion then is that for a two-dimensional  
3 system contaminant will diffuse into the rock matrix  
4 from both the vertical and horizontal cracks. This  
5 will reduce the time it takes for contaminant to  
6 diffuse through the matrix, relative to the time it  
7 would take if diffusion was only from the horizontal  
8 fractures.

9 The second point there is that the  
10 effect of two-dimensional diffusion will be similar to  
11 the effect of slightly reducing the spacing between  
12 horizontal fractures.

13 My third point is that the difference  
14 between results for one or two-dimensional diffusion  
15 will not be significant for times greater than that  
16 required to reach equilibrium. This is where the time  
17 scale issue comes in. To give you some feeling for the  
18 time scale, based on the diffusion coefficients that I  
19 have adopted in my analysis for spacing of 30  
20 centimetres between fractures or less then the time to  
21 reach equilibrium is of the order of 25 years. So if  
22 the time scale of our problem is more than 25 years it  
23 is not going to be an issue.

24 Q. Just on that last point if the  
25 time scale is going to be greater than 25 years what is  
not going to be an issue?



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2                   A.     Whether the fracture spacing,  
3 whether there are vertical fractures or whether it can  
4 come in to the specimen from vertical fractures or  
5 whether it is only modelled coming in from the  
6 horizontal fractures. In fact I have a theoretical  
7 model that takes this into account. I didn't use it in  
8 this case. It is a research model and we have examined  
9 this.

10                   Now, this is a section taken  
11 perpendicular to the flow direction. I will just for  
12 the moment put up my three-dimensional picture which is  
13 schematic 15. We just looked at a section in this  
14 plane. I would now like to take a section parallel to  
15 the direction of flow. So I am referring now to  
16 schematic No. 17 which is a schematic showing the  
17 idealized and more realistic fracture pattern for a  
18 section parallel to the flow direction. When I say  
19 more realistic I am envisaging that fractures are not  
20 going to be nice, parallel sets. In all probability  
21 you will find fractures that perhaps do something like  
22 this. I would try to indicate some of the things that  
23 would happen in a real situation. You could have  
24 fractures that are continuous. You could have  
25 fractures that narrow and widen. In some places these  
fractures are wider and narrower than others. You



1  
2 could have fractures that perhaps terminate in the  
3 vertical fracture, move down and then continue along  
4 horizontally and perhaps move up at another vertical  
5 fracture. You might have some dead-end fractures. In  
6 general the fracture spacing is not going to be the  
7 same all through the system. So, for example here, the  
8 fracture spacing between these two fractures is not the  
9 same as it is between these two. It would be  
10 unreasonable to suppose that the real situation was  
11 like this. However, what we have to consider is how  
12 can we visualize and idealize the real situation and  
13 make some quantitative estimates of what is going to  
14 happen.

15 Well, the first point I would make is  
16 that clearly the shortest distance contaminant has to  
17 travel is in a straight line. So if we adopt an  
18 idealization similar to this then the shortest distance  
19 any contaminant has to take is covered by what we are  
20 assuming.

21 Q. Dr. Rowe, when you are referring  
22 to "this" and "this" would you make it clear which side  
23 of the diagram you are referring to?

24 A. Yes, I'm very sorry. The left-  
25 hand side of the diagram is the idealization. The  
right-hand side of the diagram is a schematic of what



1  
2 might be more realistic. I am saying that in the  
3 realistic situation if we were to track a face of water  
4 or a contaminant moving from here through to here,  
5 along this path, (indicating) I think it is clear that  
6 it has to travel much further than if it were  
7 travelling in a straight line. That is the first  
8 point.

9 The second point is that if it does have  
10 to travel further obviously it has a greater surface  
11 area of rock that it is in contact with that it can  
12 diffuse into.

13 The third point that I would like to  
14 make is that even though the real situation will be  
15 variable if we analyze it as a series of parallel  
16 fractures and consider the reasonable range that the  
17 fracture spacing is likely to have in the rock, we can  
18 bracket what is likely to happen in the true situation.  
19 This is particularly true when we are looking at the  
20 time scales where saturation of the matrix pores is  
21 going to be operative.

22 So, the notes that I have at the bottom  
23 of the overhead there essentially summarize the points  
24 that I have just made.

25 Q. So that in your modelling you have  
or have you adopted the flowpaths, if you like,



1  
2 fracture description on the left-hand side?

3 A. I have adopted the fracture  
4 description on the left-hand side, that is the  
5 idealized fracture description but I have examined a  
6 reasonable range of fracture spacings to assess what  
7 the significance of fracture spacing is on the  
8 calculated contaminant movement.

9 Q. To the extent that the lines you  
10 have on the left represent the shortest distance, does  
11 that make your straight lines more or less conservative  
12 in the result?

13 A. Well, to the extent that water was  
14 travelling at the same velocity in both cases then it  
15 would be conservative, although I think in the final  
16 analysis it will not matter very much if one is looking  
17 at time scales of the order of 25 or more years.

18 Q. Now, perhaps at this point it  
19 might be appropriate to refer to paragraph 14 of the  
20 witness statement where Mr. Feenstra's comment to  
21 Mr. Tidball is referenced to the effect that -- this  
22 was Mr. Feenstra's response in essence -- that we don't  
23 know precisely which fractures carry the bulk of the  
24 groundwater. I wondered if you could comment on that  
25 at this point.

A. I would agree that we don't know



1  
2 precisely which fractures carry the groundwater and  
3 probably never will no matter how much investigation  
4 one does at the site, but the point I would make is  
5 that if you have very few fractures, if there are only  
6 one or two tiny fractures carrying any water there then  
7 the amount of flow would be so small that it wouldn't  
8 matter.

9 On the other hand, if one has a fracture  
10 system such as we are showing here with a reasonable  
11 number of fractures at spacings somewhere between, say,  
12 five and 30 centimetres which is what most  
13 investigators have suggested then we can model that  
14 extreme range between five and 30 centimetres and see  
15 what the implications of that uncertainty will be. It  
16 doesn't matter if we don't know whether it is five or  
17 30 or that in fact it probably varies between those  
18 ranges as it moves away from the site and from point to  
19 point. I would submit that as a result of my analyses  
20 I am convinced that it is not a major issue.

21 Q. Does that take us then to your  
22 overhead 17?

23 A. We have just been discussing  
24 overhead 17.

25 Q. Sorry, I meant 18.

A. I would now like to refer to



1  
2 overhead 18 which is a schematic showing the assumed  
3 zone where migration occurs.

4 Q. At Site F?

5 A. At Site F, yes, at Site F.

6 We are now approaching the point where I  
7 am going to start talking about my detailed results and  
8 for the scenario A which is discussed in the witness  
9 statement and which is the subject of my Site F report,  
10 what I have assumed is that we have a landfill and the  
11 contaminant can move down through vertical fractures  
12 without any problem beneath the landfill. What I have  
13 focused attention on is contaminant migration from the  
14 downgradient toe of the landfill. So, I have looked at  
15 modelling the contaminant migration after it has got  
16 into this route. I have tried to obtain some  
17 engineering feel for what might be expected to have  
18 happened at the Burlington Landfill and compared that  
19 with what has been observed. Then I have attempted to  
20 predict what might reasonably be expected at the  
21 proposed Site F.

22 For the purposes of the calculations I  
23 have considered contaminant movement through a zone of  
24 thickness T where I say for the purposes of calculation  
25 I have taken that thickness to be 25 metres.

Dr. Charlesworth referred to that number in his



1  
2 evidence yesterday. The primary factor that is going  
3 to emerge is going to be the Darcy velocity; that is  
4 the flow of water laterally in this material.

5 One can demonstrate that for a given  
6 Darcy velocity in the rock the actual thickness of this  
7 zone is not a major issue. So, I modelled it with 25.  
8 It wouldn't make a significant difference if I had  
9 modelled it with, say, ten. The important thing is the  
10 Darcy velocity.

11 Q. Perhaps at this point you could  
12 just go over one point you made this morning which  
13 relates again to the physical concept of diffusion.  
14 You said that certainly diffusion as a physical concept  
15 was considered and indeed modelled by Trow?

16 A. That is correct.

17 Q. What is the distinction, in your  
18 work? Did you apply it to a different aspect of this  
19 rock?

20 A. Trow in their model essentially  
21 assumed that one can neglect any vertical fractures if  
22 they were indeed there. They modelled diffusion right  
23 down through the matrix of the rock, that is straight  
24 down through the rock without any fractures at all  
25 until it got to the highly-fractured zone. The only  
thing that is different is let us suppose there are



1  
2 vertical fractures and the contaminant can get down and  
3 indeed I am being very conservative here by assuming it  
4 can get down without any difficulty. Then I am saying,  
5 okay, what happens to that contaminant? Supposing it  
6 got down into the system. What happens to it as it  
7 moves along these fractures and I am modelling the  
8 diffusion into the matrix of the rock from the  
9 fractures as the contaminant moves through these  
10 fractures downgradient?

11 Q. So have you -- your results  
12 related to that concept produced an additional or a  
13 different means or mechanism which affects the eventual  
14 impact of contamination?

15 A. Yes, I think that is true. Of  
16 course it would be nice if Trow were right. If there  
17 is a nice, 15-metre-thick zone of good shale with  
18 negligible fractures with a hydraulic conductivity of  
19  $10^{-8}$  that would be delightful, that is great. Even if  
20 it is not there, even if the material could get down  
21 through vertical fractures I am saying that there are  
22 important attenuation mechanisms that would allow, if  
23 you like, the cleaning up of the water as it moves  
24 downgradient from the landfill. I am not quibbling  
25 with Mr. Feenstra's calculation. I am saying that if  
that is there, if the weakly-fractures massive shale



1  
2 unit exists in the way that Trow said it does, that is  
3 great. Even if it doesn't, even if we adopt  
4 Dr. Charlesworth's interpretation of the  
5 hydrostratigraphy which is a more worst case than  
6 Trow's better-fit model, then everything is still okay.

7 Q. Now, you said you were approaching  
8 the point where you had some general conclusions. Is  
9 that where we are at?

10 A. The general conclusions,  
11 Mr. Chairman, that I would like to draw ...

12 Q. Before you go on, these are  
13 general conclusions with respect to scenario A?

14 A. That is correct, with respect to  
15 scenario A at Site F. This is overhead No. 6 in the  
16 witness statement, Exhibit 444.

17 Q. Scenario A being illustrated in  
18 the last overhead you referred to, page 18?

19 A. That is correct.

20 My general conclusion, briefly stated,  
21 is firstly that the speed of contaminant transport is  
22 much slower than the average linearized groundwater  
23 velocity which I have denoted here by the symbol here  
24  $V_F$ . I have tried to demonstrate that with a simple  
25 example this morning and I will be essentially  
illustrating that with respect to my results this



1  
2 afternoon.

3 My second conclusion is that the  
4 fracture porosity and the average groundwater velocity  
5 have relatively little effect for typical parameters.

6 My third conclusion is that the Darcy  
7 velocity is important. This is the important  
8 parameter. It is the amount of flow through the system  
9 carrying the contaminant with it.

10 Q. You put quotation marks around the  
11 word "velocity" which wasn't in our copy of the  
12 overhead. What is that to emphasize?

13 A. I am emphasizing the point that  
14 Dr. Charlesworth made is that the Darcy velocity isn't  
15 really a velocity, it is a flow even though we call it  
16 the Darcy velocity.

17 Q. It is in effect a volume?

18 A. That is right. It is the amount  
19 of water moving per unit area per unit time.

20 The fourth conclusion, Mr. Chairman, is  
21 that the matrix diffusion coefficient and fracture  
22 spacing are of decreasing significance at large times  
23 required for contaminant to migrate a significant  
24 distance. This is the time scale effect I talked about  
25 if we have fracture spacing at 30 centimetres. That  
core material can saturate within a period of the order



1  
2 of 25 years and if we are dealing with very large  
3 distances, as you will see in my subsequent evidence,  
4 we are dealing with times of hundreds to thousands of  
5 years for the contaminant to move past the 403 and the  
6 CNR tracks.

7 My fifth conclusion is that matrix  
8 diffusion results in a substantial attenuation of  
9 contaminants. I believe that it is an important  
10 mechanism at Site F. I am certain it is not the only  
11 mechanism, for example, with reactive contaminants.  
12 There are other mechanisms giving attenuation but this  
13 is an important mechanism.

14 Q. Now, Dr. Rowe, in your witness  
15 statement, your joint witness statement, Exhibit M-444  
16 at paragraph 5, you have also set out general  
17 conclusions arising from your October, 1987 report  
18 concerning Site F. You have told us that your report,  
19 your 1987 October report deals with scenario A.

20 A. That is correct.

21 Q. If we could look at paragraph 5 of  
22 your witness statement on page 2, perhaps the first  
23 several of these are an elaboration of the points on  
24 the overhead but I think I would like you to go over  
25 them because I believe they expand to some extent and  
then f and g perhaps go further than your overhead.



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A. That is correct.

Q. So we are at paragraph 5 of the witness statement. I would like you to read those and then tell us if there is anything further at this point.

A. My first point, point a:

"Assuming there was no matrix diffusion or dispersion, then contaminants moving along the fractures might be expected to move at the same velocity as the groundwater; however, this is not a realistic assumption for the shale at Site F."

The shale at Site F, Mr. Chairman, has a fairly high matrix porosity and for realistic diffusion coefficients there should be and there will be substantial attenuation. It is not realistic to assume that contaminant will travel at the speed of groundwater.

Point b:

"If matrix diffusion is considered at Site F, the speed of contaminant movement is much slower than the average linearized groundwater velocity."

As we will see, matrix diffusion substantially reduces



1  
2 the rate at which a contaminant will move. I tried to  
3 illustrate that this morning with our little example of  
4 people moving from the airport holding bay.

5 Point c:

6 "All other things being equal, the  
7 fracture porosity and average linearized  
8 groundwater velocity have very little  
9 effect on the rate of contaminant  
10 migration. For a given flow per unit  
11 area through the rock (expressed as the  
12 Darcy velocity), two orders of magnitude  
13 variation in fracture porosity and  
14 average linearized groundwater velocity  
15 had no significant effect on the rate of  
16 contaminant movement."

17 I will demonstrate that to you with some of my results.

18 Point d is:

19 "The Darcy velocity is one of the key  
20 variables controlling the concentration  
21 of contaminant at a given point  
22 downgradient of the landfill at a given  
23 time."

24 The Darcy velocity is the product of the hydraulic  
25 conductivity and the hydraulic gradient.

Point e is that:



1  
2 "Fracture spacing and the diffusion  
3 coefficient are of importance at small  
4 times and at locations close to the  
5 landfill; however, at larger times and  
6 at distance from the landfill,  
7 reasonable uncertainty regarding the  
8 magnitude of either of these quantities  
9 had very little effect on the calculated  
10 impact."

11 Again, this is related to this time scale of the  
12 problem, the time it takes contaminant to move from the  
13 fractures into the matrix of the rock.

14 We are now moving into more specific  
15 conclusions. Point f is:

16 "Considering the effect of matrix  
17 diffusion, there is substantial  
18 attenuation of contaminant as the flow  
19 occurs through fractures in the shale;  
20 the concentration of contaminant 300 or  
21 more metres from the landfill is very  
22 small."

23 Point g is:

24 "The proposed landfill will have minimal  
25 impact on deep groundwater quality;..."

Q. Perhaps it is appropriate at this



1  
2 point to understand what you have meant by deep  
3 groundwater quality having regard to Dr. Charlesworth's  
4 sketch, Exhibit M-445.

5 A. Exhibit M-445 essentially  
6 illustrates what Dr. Charlesworth has called his  
7 shallow zone which is a zone where he suggests  
8 contaminant is most likely to move. I should point out  
9 that there are several ways one can divide what are  
10 three different flow systems in this Site F.  
11 Dr. Charlesworth has essentially referred to a very  
12 shallow system; that is, for example, water that enters  
13 on the site and re-emerges on the site. Also I think  
14 he was or would classify the rind, this freshwater rind  
15 as a very shallow system. I have, in my terminology,  
16 referred to that as the shallow system so that my  
17 shallow system is Dr. Charlesworth's very shallow  
18 system. This shallow system or shallow zone  
19 Dr. Charlesworth has shown here ...

20 Q. On Exhibit M-445?

21 A. ... on Exhibit M-445 is what I am  
22 referring to in my witness statement and in my report  
23 as deep groundwater. There is obviously a very deep  
24 system below that which we are not concerned about.

25 Q. If we wanted to understand  
paragraph g of paragraph 5 of your witness statement in



1  
2 the context of Exhibit M-445, would it be appropriate  
3 to in fact take out the words "deep groundwater" and  
4 insert "part of the shallow zone"?

5 A. That is correct.

6 Q. As described by Dr. Charlesworth  
7 in Exhibit M-445?

8 A. That is correct.

9 MR. ESTRIN: Perhaps, Mr. Chairman and  
10 everyone else, it might be appropriate for you to amend  
11 your witness statement at this time so you don't have  
12 any future confusion over this issue.

13 DR. ROWE: I would point out that I am  
14 consistent in my use.

15 MR. ESTRIN: Q. You are consistent and  
16 it is simply that your terminology is not in line with  
17 how Dr. Charlesworth has decided to name it. The fact  
18 is we are talking about -- we now know what you are  
19 talking about in relation to his.

20 To correspond to Exhibit M-445 the  
21 appropriate words would be to have minimum impact on  
22 the part of the shallow system as described in Exhibit  
23 M-445?

24 DR. ROWE: A. That would be correct in  
25 Dr. Charlesworth's terminology.

DR. KINGHAM: Where are you suggesting



1  
2 that?

3 MR. ESTRIN: In paragraph g, the second  
4 line:

5 "The proposed landfill will have minimal  
6 impact on part of the shallow zone as  
7 described..."

8 I think there will be some consistent changes of a  
9 similar nature to be made in the balance of this to be  
10 consistent.

11 MR. LANCASTER: Is that a change or just  
12 an explanation? In other words, he used a different  
13 terminology.

14 MR. ESTRIN: That's right. We are not  
15 making a change, there is no difference in opinion.  
16 It's simply to make the terminology the same.

17 MR. LANCASTER: You might come across it  
18 later on.

19 DR. ROWE: In my Site F report I used  
20 the same terms as I used in my witness statement. So  
21 when I refer to the deep groundwater quality, I refer  
22 to the material which moves downgrade of the site and  
23 eventually disappears into Hamilton Harbour or Lake  
24 Ontario, wherever it goes down there. When I am  
25 talking about the shallow groundwater system, I am  
talking about the freshwater rind. So I say here...



1

2

3

MR. ESTRIN: Q. When you are talking  
about it in your report?

4

DR. ROWE: A. In my report.

5

6

7

8

Q. For our purposes where we are now  
let us talk about paragraph g. The proposed landfill,  
you say, will have minimal impact on, in effect, the  
shallow zone as described in Exhibit M-445?

9

A. This is correct.

10

Q. Let us continue to read this.

11

12

13

14

A. "... thus, in the event that there  
was a discharge of this groundwater into  
the shallow groundwater system ..."

By that I mean the freshwater lens.

15

16

17

18

19

20

21

Q. So for clarification:

"In the event that there was a discharge  
of this water into the very shallow  
groundwater or (freshwater lens)..."

A. "...southeast of Highway 403, the  
impact of the landfill on the shallow  
groundwater system..."

22

That is the same freshwater lens:

23

"... would also be minimal.

24

25

Furthermore, upward movement of deep  
groundwater..."

By that I mean water in what Dr. Charlesworth has



1  
2 referred to as his shallow zone; that is the water  
3 moving from the landfill to beneath the 403.

4 DR. KINGHAM: Just at that point do you  
5 mean then furthermore upward movement of the shallow  
6 zone water as described in 445 through the till?

7 DR. ROWE: That is correct.

8 "... would result in additional  
9 attenuation of and improvement to the  
10 deep groundwater quality."

11 MR. ESTRIN: Q. It would be appropriate  
12 to amend that to read "attenuation of an improvement to  
13 the shallow system"?

14 DR. ROWE: A. Consistent with 445.

15 Q. To take out the end of it and put  
16 in any discharge from the shallow system. Perhaps  
17 there is one more change of this nature.

18 A. I will clarify that:

19 "In the event that the deep  
20 groundwater..."

21 By that I mean from Dr. Charlesworth's shallow zone in  
22 M-445:

23 "... did discharge in this manner, it is  
24 expected that the impact of the  
25 naturally poorer quality of this  
groundwater would be far more



1  
2 significant than any impact due to  
3 contaminants in the groundwater which  
4 originated from the proposed Halton  
5 Landfill."

6 DR. KINGHAM: I understand what that  
7 says but I don't understand it in a sense in terms of  
8 what Dr. Charlesworth told us earlier. I thought he  
9 delineated the shallow zone, the deeper zone on the  
10 basis that anything below his dotted line was very  
11 saline and very poor quality. Are you not telling us  
12 here that with the amendments you are proposing that it  
13 is the shallow zone groundwater that is of such low  
14 quality that it would improve by being discharged? You  
15 confuse me a bit.

16 DR. ROWE: I'll ask Dr. Charlesworth to  
17 speak to that.

18 DR. CHARLESWORTH: When I was referring  
19 to the shallow zone I was referring specifically to the  
20 area beneath the site and just downgradient of the  
21 site. I feel as you move down beneath the plain to the  
22 south and towards the lake this whole issue becomes  
23 somewhat more tenuous in terms of distinguishing the  
24 two. I in fact, I think it would be wisest at this  
25 point not to actually change the text of that, maybe  
refer to it at this point or know that when Dr. Rowe



1  
2 refers to the deep groundwater he is referring to the  
3 water from the shale.

4 DR. KINGHAM: Perhaps the Board could  
5 invite you to consider paragraph g and put it in a form  
6 of words that it will be crystal clear to us what is  
7 meant.

8 MR. ESTRIN: Thank you. I think that  
9 would be appropriate.

10 Q. Now, Dr. Rowe, just on that last  
11 point, the statement Dr. Charlesworth talked about, the  
12 freshwater lens or the rind or whatever it is called...

13 DR. ROWE: A. That's right.

14 Q. ... in the overburden in the plain  
15 well south of 403. The last part of paragraph g speaks  
16 to the potential of groundwater below that, more saline  
17 groundwater below that?

18 A. That is correct. I am saying that  
19 if water is coming up from -- unfortunately I am having  
20 trouble with precisely what one defines as "deep". If  
21 the water now comes up from the shale which we know is  
22 highly saline into this freshwater rind, I am saying  
23 that the impact of that water from the shale is likely  
24 to be greater than any impact of contaminants that may  
25 have been carried in that water in the shale when it  
eventually gets down to wherever it is coming out.



1  
2 Once it has gone past Highway 403 the contaminant has  
3 been reduced to some very low levels as I will  
4 illustrate.

5 Q. Does that help? Thank you for  
6 that invitation because we didn't appreciate that there  
7 was this dichotomy of terminology until the last  
8 minute, so to speak. It occurred to me that would be  
9 the proper way to handle it.

10 All right now, where does that bring us  
11 to? We had gone over then your general conclusions  
12 with respect to scenario A?

13 A. That is correct.

14 Q. Can we -- are you almost ready  
15 then to turn to the steps taken to arrive at those  
16 conclusions?

17 A. Yes.

18 Q. Would it be appropriate at this  
19 point, before we get to these steps, to comment on the  
20 model that you used?

21 A. Yes, I think that may well be  
22 appropriate. Mr. Chairman, the model that I used to  
23 simulate contaminant migration called scenario A at  
24 Site F was actually a combination of two existing  
25 models. The first was a model proposed some years ago  
by Sudicky and Frind called "Matrix Diffusion as



1  
2 Contaminant is Transported Along a Series of Parallel  
3 Fractures." They assumed that the initial  
4 concentration within the landfill remained constant so  
5 they had a constant source. In earlier work that I had  
6 done we developed a model which takes account of the  
7 finite mass of contaminant and we referred to that  
8 paper in the testimony yesterday. What I did was I  
9 combined this finite mass of contaminant concept with  
10 the concept proposed some years ago by Sudicky and  
11 Frind to model both the finite mass of contaminant and  
12 the matrix diffusion as the contaminant moves along the  
13 fractures.

14 Q. We will go then to the overhead  
15 which is No. 19.

16 A. I am referring to figure 19 in my  
17 witness statement under tab 2 which outlines the steps  
18 which I have taken in this study using scenario A at  
19 the site, at Site F. The first thing that I did,  
20 Mr. Chairman, was having read Trow's reports and before  
21 the better-fit model arrived I had looked at the flow  
22 or recharge they had into the system. I did a quick  
23 calculation assuming that we had a recharge of 14  
24 millimetres per annum and that the flow was passing  
25 through a 25-metre-thick zone. This indicated a flow  
or Darcy velocity of about 0.7 metres per annum. I



1  
2 looked at what the implications might be if the flow in  
3 the fractured rock was of that order. This doesn't  
4 have to be related directly to Trow's model. I am  
5 examining what the implications would be if the Darcy  
6 velocity were 0.7 metres per annum. One way you could  
7 get that Darcy velocity for example is if the gradient,  
8 the lateral gradient of 0.035 suggested by  
9 Dr. Charlesworth, then this would correspond to a  
10 hydraulic conductivity of  $6.3 \times 10^{-5}$ . That is another  
11 way of interpreting what the Darcy velocity is. It  
12 really doesn't matter how you arrive at that Darcy  
13 velocity; it is the Darcy velocity that will become  
14 important.

15                   So, I calculated the contaminant plume  
16 that one might expect after 15 years migration at the  
17 Burlington Landfill using a Darcy velocity of 0.7  
18 metres per annum. At this same time I also examined  
19 the effects of uncertainty regarding fracture opening  
20 size and fracture spacing. I then estimated a lateral  
21 flow based on the information provided to me by Geocon  
22 and Dr. Charlesworth to be about 0.05 metres per annum.  
23 That is based on a hydraulic conductivity of  $4.5 \times 10^{-6}$   
24 which Dr. Charlesworth referred to in his testimony  
25 yesterday and a hydraulic gradient of 0.035. Again, it  
doesn't matter what combination of gradient and



1  
2 hydraulic conductivity you take to get this Darcy  
3 velocity, it is the Darcy velocity that is important.

4 With that Darcy velocity I also examined  
5 the potential for migration from the Burlington  
6 Landfill and then subsequently examined the potential  
7 for attenuation in the fractured zone south of the  
8 proposed Site F. I looked to see what the implications  
9 of this velocity would be with respect to the  
10 contaminant migration one might expect from Burlington  
11 and then I looked at what the implications would be for  
12 the proposed Site F.

13 Finally, I considered what I am calling  
14 my worst case scenario for a flow of 0.125 metres per  
15 annum. I examined once again the Burlington Landfill  
16 and Site F. I call this my worst case because I think  
17 -- it is my opinion that this is about as bad as one  
18 could expect things to be. I indicated a moment ago  
19 that I did look at the implications of a Darcy velocity  
20 of 0.7 metres per annum with respect to the Burlington  
21 Landfill and based on that examination I concluded that  
22 this is an unrealistic velocity, that it is not going  
23 to be that high. My worst case which I think is  
24 reasonable is 0.125 metres per annum. My estimate of  
25 the most likely is in the order of 0.05 metres per  
annum as a Darcy velocity.



- 1
- 2 Q. I have made a note on that page,
- 3 that overhead with respect to the Darcy velocity which
- 4 you worked with in No. 1 of 0.7 and at the end you
- 5 considered that not to be a realistic velocity?
- 6 A. That is correct, I do not consider
- 7 0.7 to be a realistic velocity based on the evidence I
- 8 have before me.
- 9 Q. With respect to the Darcy velocity
- 10 of point No. 6 of 0.125 metres per annum that is, you
- 11 said, a worst case?
- 12 A. I do not expect the situation to
- 13 be worse than that and I do expect it to be better. In
- 14 all probability it will be better.
- 15 Q. With respect to the Darcy velocity
- 16 found in point No. 4 of 0.05 metres per annum?
- 17 A. That appears -- that corresponds
- 18 to the data given to me by Dr. Charlesworth but over
- 19 and above that it seems to be consistent with what is
- 20 observed in terms of contaminant migration or lack
- 21 thereof at the Burlington Landfill.
- 22 Q. I think you introduced the words a
- 23 minute ago "most likely" of the three?
- 24 A. Yes, I think that is -- I am not
- 25 saying it is going to be precisely 0.05 but I think the
- likely order is in the range of 0.05.



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Q. Now, you have considered a number of parameters?

A. I am referring now to overhead No. 20, Mr. Chairman, which is a summary of the parameters that I considered. This is discussed in some detail on pages 26 to 33 of Exhibit 440. I was going to go through and essentially summarize for you the parameters that I had used and which are discussed in detail on those pages of my Site F report. As I indicated, there are essentially two landfills that I gave consideration to. One is the proposed Halton Landfill at Site F and I took approximate dimensions for the purposes of calculation to be a length, that is a length in the direction in which the flow is going to occur of 1,250 metres and a width of 400 metres. It does not in fact matter whether these numbers are precisely those values. For the purposes of looking at the Burlington Landfill, I considered the portion of the Burlington Landfill which does not have an underdrain system and the dimensions that I took were a length of 800 metres and a width of 250 metres. So I am looking at a rectangular area. The reality of course is that it is not a perfect rectangle but these parameters represent a reasonable approximation. So, those are the dimensions I looked at.



1  
2 As I indicated, I looked at three Darcy  
3 velocities. The first of those was 0.7 metres per  
4 annum and the number originally came from a calculation  
5 I did based on Trow's report although it doesn't have  
6 to be related to that. As I indicated, another way of  
7 getting exactly the same Darcy velocity would be to  
8 have a gradient of 0.035 and a hydraulic conductivity  
9 of  $6.5 \times 10^{-5}$  centimetres per second. I looked at 0.05  
10 metres per annum which is expected conditions based on  
11 the information provided to me by Dr. Charlesworth and  
12 which turned out to be reasonably consistent with what  
13 information is available with respect to contaminant  
14 migration from Burlington Landfill. I looked at my  
15 worst case of 0.125 metres per annum.

16 Now, the worst case of 0.125 metres per  
17 annum can be viewed several ways. One could for  
18 example use the gradient that Dr. Charlesworth  
19 indicated of 0.035 in which case this would correspond,  
20 this velocity of 0.125 metres per annum would  
21 correspond to a hydraulic conductivity of  $1.1 \times 10^{-5}$ .  
22 Another way of viewing exactly the same Darcy velocity  
23 would be to say let us suppose that mounding occurred  
24 at Site F. Now, if one were to take an incredibly  
25 extreme situation and assume mounding to the top of the  
landfill which I think is very unlikely at Site F then



1  
2 that would give us a gradient of the order of 0.088.  
3 That gradient combined with the hydraulic conductivity  
4 of  $4.5 \times 10^{-6}$  centimetres per second mentioned by  
5 Dr. Charlesworth gives us exactly the same Darcy  
6 velocity. Again I would make the point that there are  
7 various ways of interpreting what the Darcy velocity  
8 means or arriving at that Darcy velocity. Irrespective  
9 of how you get to it, it is the Darcy velocity that is  
10 important. So, in a sense these results look at the  
11 effect of uncertainty with respect to hydraulic  
12 conductivity and with respect to hydraulic gradient at  
13 the same time.

14 Just to give you some idea of what these  
15 flows might mean with respect to recharge, if one takes  
16 the length of the landfill of 1,250 metres and assumes  
17 that the flow is through a 25-metre thickness of rock  
18 then a Darcy velocity of 0.7 metres per annum  
19 corresponds to a recharge of 14 millimetres per annum.  
20 As I said, my initial recharge I got from approximating  
21 numbers given in Trow's report. If we were to look at  
22 the velocity of 0.05 metres per annum with the same  
23 geometric conditions this would correspond to a  
24 recharge of one millimetre per annum over the entire  
25 site. If we were to look at a Darcy velocity of 0.125  
metres per annum under the same geometric conditions it



1  
2 corresponds to a recharge of 2.5 millimetres which  
3 coincidentally is close to what Mr. Sobanski said the  
4 recharge would be for their better-fit model. I point  
5 out that is purely coincidence and nothing more.

6 DR. KINGHAM: Just at that very point so  
7 we understand quite clearly, you put the words "worst  
8 case" in quotation marks because that is really your  
9 worst case as opposed to Mr. Sobanski's case which  
10 would be a worst case in an absolute sense?

11 DR. ROWE: I would point out,  
12 Mr. Chairman, Dr. Kingham, that Mr. Sobanski wasn't  
13 modelling a hydrogeology system that I am looking at.  
14 I am treating Dr. Charlesworth's system which doesn't  
15 have the weakly fractured massive shale unit as a nice,  
16 distinct unit. I simply said for a starting point let  
17 us use the recharge that Trow got from their model.  
18 This is not related other than in that way to Trow's  
19 model. This is not really Trow's worst case.

20 The fracture spacings I looked at was  
21 typically five to 30 centimetres although I did  
22 consider one case of 1.2 metres just to see what might  
23 happen. The fracture opening size that I typically  
24 looked at was 30 to 500 microns, although I did look at  
25 one case of five microns. The fracture porosity that I  
looked at ranged in general from 0.0001 to 0.01. Again



1  
2 I also looked at a very extreme case in one instance of  
3 0.000025. I examined what the sensitivity of the  
4 results was to fracture porosity.

5 The matrix porosity is something we can  
6 get a much better handle on. You can see there are  
7 many orders of magnitude and uncertainty, if you like,  
8 regarding fracture porosity. The matrix porosity is  
9 something that is much easier to determine. The test  
10 and perhaps I should reiterate here that we took  
11 samples of shale from Site F, we took them back to our  
12 laboratory, we determined what the matrix porosity was  
13 of those samples and we performed tests to determine  
14 what the diffusion coefficient is likely to be in that  
15 rock. We actually have our own tests which indicated a  
16 porosity of the shale in the 0.1 to 0.11 range. The  
17 value that I actually used in the analysis was 0.08. I  
18 adopted a smaller value to be conservative. In Trow's  
19 report they quote a matrix porosity of 0.1. That is  
20 the porosity that Mr. Feenstra used in his contaminant  
21 migration analysis through the weakly fractured massive  
22 shale unit.

23 It is perhaps worth mentioning here that  
24 in the witness statement under paragraph 12 I refer to  
25 Exhibit N-253.

MR. ESTRIN: Q. That is right and.



1  
2 that was laboratory values that I think Mr. Feenstra  
3 used. It is the data from Chemical and Geological  
4 Laboratories Limited which noted on my copy says in  
5 handwriting "Analysis of core taken from Bayview Park."  
6 Do you want to comment on if the porosities recorded in  
7 that analysis are consistent or inconsistent with your  
8 test data and assumptions?

9 DR. ROWE: A. Mr. Chairman, we have in  
10 front of us Exhibit M-253 and three porosity values  
11 quoted. It seems that this has been done in a  
12 laboratory in Alberta. The values quoted there are  
13 0.105, 0.073, 0.078. I do not know exactly how those  
14 tests were performed. However, the numbers appear to  
15 be generally consistent with the value that I used in  
16 my analysis. I would add that I suspect these numbers  
17 may be a little low because the rock had to be  
18 transported from site in Burlington to Alberta. In  
19 doing so it is quite likely that the rock dried out  
20 somewhat, some of the water dried out of the rock. If  
21 that were the case then the values of porosity they got  
22 could well be on the low side. So I suspect their  
23 values, perhaps a little low but even if they are right  
24 they are reasonably consistent with the value that I  
25 have used. In fact, if you average the values they got  
with the values that we got from our test you get a



1 .  
2 value of 0.1. So Trow were pretty wise or pretty lucky  
3 in their choice of 0.1.

4 Q. You chose to use for the purposes  
5 of your calculations 0.08?

6 A. Yes. On the basis of the evidence  
7 I have before me I believe that the true porosity is of  
8 the order of 0.1. For the purposes of analysis I  
9 modelled it using 0.08 and that is conservative, that  
10 is a worst case than the real value which is probably  
11 about 0.1.

12 The diffusion coefficient is another  
13 parameter that one has to deal with. I, as I  
14 mentioned, had a sample delivered to the laboratory.  
15 Dr. Charlesworth was there at the sampling and I  
16 performed -- had performed -- a graduate student and  
17 myself did work to determine diffusion coefficients.  
18 This is reported in Exhibit 441. I would like, if I  
19 could, Mr. Chairman, to move for a few moments to  
20 Exhibit 441 and specifically to figure 4 initially.

21 Q. Four forty-one is the unbound  
22 document entitled "Laboratory Determination of Chloride  
23 Diffusion Coefficient in Intact Shale", one of the  
24 documents filed prior.

25 MR. LANCASTER: It's an appendix to  
440?



1  
2 DR. ROWE: That is correct. I don't  
3 want to spend a great deal of time on this appendix,  
4 Mr. Chairman, it is only an appendix, but I think it  
5 might be useful for the Board to actually have a look  
6 at some results of tests which show that diffusion does  
7 indeed occur in this shale, so I would like to refer to  
8 the results of the first test we performed which is  
9 shown on figure 4.

10 Shown on this figure on the horizontal  
11 axis is the concentration of chloride expressed in  
12 grams per litre. On the vertical axis is depth through  
13 the sample. What we did, Mr. Chairman, is we took a  
14 sample of the shale and we cut it into a number of  
15 sections. We performed a total of three diffusion  
16 tests. At the ends of each of the samples on which we  
17 performed the diffusion test we determined what the  
18 background concentration was. So we determined what  
19 the concentration of chloride was at the two ends and  
20 then this dotted line is a line drawn between the  
21 background values in this particular case.

22 We then placed that sample of shale in  
23 contact with distilled water and allowed chloride to  
24 diffuse out of the shale into the water. As it  
25 diffused out the concentrations of chloride within the  
sample decreased. We terminated the test after 45 days



1  
2 and determined the concentration at various locations  
3 in the sample. We sliced the sample up and we  
4 determined the concentration of each of those slices.  
5 In addition, we had a measurement of what the chloride  
6 concentration was in the reservoir that was in contact  
7 with the shale. Most of these points are in the shale  
8 itself and the point at the very top is the  
9 concentration in the reservoir of water in contact with  
10 the shale. As with most experimental data there is  
11 some scatter. The porosity of this was 10.6 per cent  
12 of this particular sample. After we finished the test  
13 and determined what the concentrations were, we used a  
14 theoretical model to put theoretical curves to the  
15 data. Shown here are the results of three different  
16 curves, three different diffusion coefficients. You  
17 can see that within or without too much problem one can  
18 define a diffusion coefficient for the shale. It may  
19 be somewhere between  $1.4$  and  $1.8 \times 10^{-6}$  cm<sup>2</sup>/s. One can  
20 obtain a reasonable fit to that data and what is even  
21 more important, Mr. Chairman, is the fact that quite  
22 clearly chloride had diffused out of the sample into  
23 the source water. So there is definitely, without any  
24 question, potential for diffusion to occur in this  
25 shale and substantial diffusion. In 45 days you can  
see a very substantial drop in the concentration of



1  
2 chloride in that sample. As I say we did three tests.  
3 I will very briefly show the other results. They show  
4 the same thing but just to illustrate the level of  
5 repeatability, this test is after 65 days. This  
6 particular sample had a porosity of about 11.3 per cent  
7 and again the range of  $1.4$  to  $1.8 \times 10^{-6}$  provides a  
8 reasonable fit to the data allowing for inevitable  
9 experimental scatter.

10 Figure 6 shows simply one more of the  
11 same. This was a repeat, a duplicate if you like of  
12 model 2. It was also terminated at 65 days and one  
13 sees the same trend so that we have some idea of what  
14 the diffusion coefficient is in this sample of the  
15 shale and perhaps more importantly we have very clear  
16 evidence that diffusion does indeed occur in this  
17 shale.

18 Now, I would like to if I could go back  
19 now to my overhead No. 20 in my witness statement, the  
20 summary of parameters. I am returning to that overhead  
21 that is No. 20 in the witness statement which is  
22 Exhibit 444.

23 MR. LANCASTER: I am wondering if it  
24 would be inconvenient for you to take a break.

25 DR. ROWE: Can I just make one final  
point, Mr. Chairman, and I think it will be a very



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2

convenient point?

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4

MR. LANCASTER: I thought you were going to and that is why I asked.

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DR. ROWE: If I could just finish up on this diffusion coefficient in shale. Based on the tests, my best estimate of what the diffusion coefficient in shale is, it's about  $1.5 \times 10^{-6}$  cm<sup>2</sup>/s. You saw the level of uncertainty associated with that number. That is not, however, the value I have used in my analysis. To be conservative I adopted a value of  $6 \times 10^{-7}$ . That is approximately two-and-a-half times smaller. As I indicated in my discussion this morning, the lower the diffusion coefficient, the more conservative. So I have laboratory data. I think based on the data I have got a reasonable value but nevertheless I modelled this value and I would also point out that Trow in their modelling used a value of  $5 \times 10^{-7}$  cm<sup>2</sup>/s. This is the value that I used and indeed as I will demonstrate to you later in my testimony I also did a what if; what if it were even half of that to see what the effect of this would be.

I think at that point, Mr. Chairman, we might ...

DR. KINGHAM: Before we rise I can't resist bringing to the attention of counsel who were



1  
2 not here last week the great difficulty that the Board  
3 faces because last week Mr. Lederer explained to us  
4 very carefully that if landfills are McDonalds and  
5 roosting areas are schools then cars are birds and  
6 airplanes are people. Today, Dr. Rowe, you have  
7 explained that if landfills are airports and fissures  
8 are corridors then groundwater velocity is conveyor  
9 belts and contaminants are people, so now I don't know  
10 whether people are contaminants or people are airplanes  
11 but I think on that note, maybe we should have a  
12 coffee.

13 --- Recess

14 MR. LANCASTER: Please be seated.

15 MR. ESTRIN: Q. All right, Dr. Rowe,  
16 you can proceed.

17 DR. ROWE: A. Mr. Chairman, just before  
18 the break I was going through and outlining,  
19 summarizing for the benefit of the Board the parameters  
20 that I used in my calculations. The diffusion  
21 coefficient that I actually used in my analysis at Site  
22 F for the shale was  $6 \times 10^{-7}$  cm<sup>2</sup>/s. It is of some use  
23 on occasion to define a quantity which we call the  
24 tortuosity and I am going to refer now both to overhead  
25 20 which I have been discussing and overhead 21,  
essentially a transition from those two. We have



1  
2 tortuosity defined as the ratio of the diffusion  
3 coefficient in the matrix of the material whether it is  
4 a shale or a clay or whatever, divided by the diffusion  
5 coefficient for that species in pre-solution. So, I  
6 have divided my diffusion coefficient of  $6 \times 10^{-7}$  by  
7 the diffusion coefficient in pre-solution which I got  
8 from a standard chemistry text and arrived at a  
9 tortuosity. This is just giving us some idea of how  
10 the presence of the particles slow down the movement of  
11 the species of the contaminant, in this case chloride.  
12 I am not suggesting that this is the true value because  
13 remember there are the values that we got from the test  
14 but this is based on my design value of diffusion  
15 coefficient which I have indicated earlier is a  
16 conservative value based on the available data.

17           The diffusion coefficient for benzene in  
18 pre-solution from a text is given there at  $10^{\circ}\text{C}$ . To  
19 get an idea of what the diffusion coefficient of  
20 benzene would be in shale I multiplied the diffusion  
21 coefficient in presolution which is this number here by  
22 the tortuosity and arrived at a diffusion coefficient  
23 of  $3.6 \times 10^{-7}$  cm/s. This is the value I used in my  
24 calculations. It is, I believe, a conservative value  
25 for two reasons: firstly, you will recall that I had  
already factored my diffusion coefficient in getting



1  
2 the tortuosity. Secondly, there is evidence to suggest  
3 that organics such as benzene might actually diffuse  
4 faster than you would expect based on the tortuosity.  
5 That is because the movement of chloride is, to some  
6 extent, controlled by the fact that one needs a cation  
7 to move with it. So we are talking about charge  
8 spacing the chloride has to move, something has to move  
9 with it to maintain a charge balance. This can slow  
10 down chloride but nevertheless I didn't take that into  
11 account. It is conservative not to take it into  
12 account. This is, I believe, a conservative value for  
13 benzene. I will be talking specifically in my  
14 evidence, Mr. Chairman, about the diffusion of chloride  
15 and of benzene to give you some idea of how a  
16 conservative species might behave and how an organic  
17 such as benzene might be expected to behave for both  
18 the Burlington Landfill and Site F.

19 Benzene is a species that might be  
20 expected or would be expected to interact with the  
21 organic carbon in the shale and Mr. Feenstra has spoken  
22 to sorption of organics and he or in Trow's report they  
23 have a fraction of organic carbon of 0.18 per cent  
24 quoted. That is the value I used. Based on  
25 correlations in the literature I deduced a partitioning  
coefficient which reflects the level of sorption of



1  
2 benzene one would expect in the shale and I came up  
3 with a parameter of  $0.19 \text{ cm}^3/\text{g}$  and from that I deduced  
4 a retardation factor and I think you have heard about  
5 retardation factors in earlier evidence. Based on the  
6 uncertainty I would expect our value for benzene to lie  
7 between 5.5 and seven. To be conservative I adopted a  
8 value of 5.5. I think the important thing here is that  
9 I am just using benzene as an indication of how an  
10 organic with a retardation factor of this order would  
11 behave. One needs initial concentrations in any  
12 calculation.

13 For the purposes of looking at how  
14 chloride might behave I assumed an initial  
15 concentration of chloride of 1,500 milligrams per litre  
16 which is a value that Trow used in their report and for  
17 benzene I used an initial concentration of 150  
18 micrograms per litre which is again a value that I  
19 obtained from Trow's report, in particular from page 92  
20 of Trow's report which is Exhibit H-40.

21 I have indicated that one should be  
22 considering the mass of contaminant within the  
23 landfill, particularly if you are concerned with the  
24 long-term effects of the landfills. I am going to be  
25 talking about this in some more detail when I come to  
Site D but for the purposes of my calculation of the



1  
2 Halton Landfill, that is Site F, I analyzed it using a  
3 mass of chloride of 7,800 tonnes. I obtained that mass  
4 by integrating essentially beneath the curve for  
5 concentration, variation for time presented by Trow and  
6 making some very, what I believe, very conservative  
7 assumptions. So I have, I believe, been very  
8 conservative in using a mass of 7,800 tonnes of  
9 chloride for the Halton Landfill.

10 In my analysis of Site D I have been far  
11 less conservative. I have used a value of 4,400  
12 tonnes. This is a deliberate inconsistency. I believe  
13 a more realistic value is about 4,400 and I will  
14 elaborate on that more when I discuss Site D. However,  
15 to be conservative with Site F since I was essentially  
16 saying it was okay I thought I should be very  
17 conservative, I used a value of 7,800 tonnes.

18 For the Burlington Landfill, it is  
19 somewhat smaller, particularly the section without an  
20 underdrain and one can't justify being quite as  
21 conservative because we are trying to look at how that  
22 landfill is actually behaving. I used a mass of 2,200  
23 tonnes. In fact for the Burlington Landfill this is  
24 not a particularly critical issue because I am only  
25 concerned with 15 years. It has only been there about  
15 years and there is not a lot of time for the



1  
2 concentration of contaminant to decrease. When one is  
3 looking at a much longer time span which I am for  
4 Halton then the mass becomes more important.

5 Based on an assumption that the mass of  
6 contaminant is proportional to the initial  
7 concentrations one can reduce the mass of benzene and  
8 correspondingly it would be 0.78 tonnes for Site F and  
9 0.22 tonnes for Burlington. Again I believe in the  
10 case of Site F this is a very conservative assumption.

11 So what I have defined here are the  
12 initial concentrations in the landfill itself and the  
13 assumed mass of contaminant that is available either to  
14 be collected by the leachate collection system or for  
15 transport into the shale.

16 I would now like to refer, refer back to  
17 overhead 18 in my witness statement to elaborate on  
18 something I hadn't discussed previously. You will  
19 recall, Mr. Chairman, that I indicated I had assumed  
20 that the contaminant would get down into the shale  
21 beneath the landfill without any difficulty. Then I  
22 have modelled, if you like, the movement of  
23 contaminants downgradient of the toe of the landfill.  
24 You can picture, I am sure, that if contaminant is  
25 coming down through these fractures it is going to be  
diffusing into the matrix of the rock beneath the



1  
2 landfill. To try and make at least some account of  
3 this I performed calculations to get what I am  
4 referring to as an adjusted concentration which I  
5 denote by the symbol  $C_o^*$ , \* being adjusted. It is  
6 adjusted to take account of dilution, if you like, that  
7 will occur as contaminant comes down here and diffuses  
8 into the matrix of the rock beneath the landfill. My  
9 calculation is, I believe, very conservative because  
10 what I did was I essentially calculated what volume of  
11 leachate could correspond to my mass of contaminant and  
12 I mixed that with the amount of fresh water, I use  
13 fresh in inverted commas because we know it is  
14 contaminated water but not by the landfill. I mixed  
15 this amount of leachate with the volume of water in the  
16 pores of the rock beneath the landfill to get an  
17 adjusted concentration. The reason I say this is very  
18 conservative, Mr. Chairman, is because I used the total  
19 amount of leachate that is available whereas in fact  
20 most of that leachate will be collected by the leachate  
21 collection system. For the purposes of this  
22 calculation I didn't take that into account. That is  
23 a very conservative thing to do. This gave rise to an  
24 adjusted concentration of chloride of 1,260 milligrams  
25 per litre for Site F which I have called the Halton and  
1,180 for the Burlington Landfill. The difference



1  
2 being because there is a different area of the landfill  
3 that we are looking at.

4 DR. KINGHAM: Could you back up for one  
5 minute from what you just said to the slide before that  
6 when you gave a figure of 0.78 tonnes of benzene? Are  
7 you telling us that is your assumption of 100 per cent  
8 of the benzene that would be in all the waste?

9 DR. ROWE: That is correct, Dr. Kingham.

10 DR. KINGHAM: As opposed to that weight  
11 of benzene that has been lost by not being collected by  
12 the underdrains?

13 DR. ROWE: That is correct, this is what  
14 I am saying is the total.

15 I am referring now to overhead No. 22 of  
16 the witness statement which summarizes the adjusted  
17 concentrations that I actually used in the analysis for  
18 both chloride and benzene. I would also make a note  
19 about why I said that we would expect mixing with the  
20 rock. This is related to the time scale that I have  
21 previously alluded to. I indicated before that over a  
22 25-year period I don't think that fracture spacing is  
23 an issue. Here I am going one step further and saying  
24 that within a period of less than a year one would  
25 expect 90 per cent of the mass that is going to move  
into the rock matrix beneath the landfill to occur.



1  
2 That is within one year of the leachate being around  
3 the rock the contaminant would move in with a fracture  
4 spacing of five centimetres. If the fracture spacing  
5 was in the order of 30 centimetres then approximately  
6 90 per cent of the mass that is likely to move into the  
7 rock would occur in about ten years. The 90 per cent  
8 is representing most of what can get in. As the  
9 concentration in the fractures becomes close to what it  
10 is in the matrix then the diffusion process slows down  
11 and that is why it takes of the order of another 15  
12 years for approximately complete equilibrium to occur.  
13 Most of it the action happens within about ten years  
14 for a fracture spacing of 30 centimetres.

15 So that really sets the scene I think  
16 for the results that I am going to present to the  
17 Board.

18 MR. ESTRIN: Q. And the results that  
19 you are now going to discuss are with respect to still  
20 scenario A?

21 DR. ROWE: A. That is correct, yes.

22 Mr. Chairman, I am now going to refer to  
23 overhead No. 23 which is in fact a marked-up copy of a  
24 figure from my Site F report which is Exhibit 440.  
25 This in fact is figure 4 from that exhibit. I am going  
to try and work through and explain to the Board what



1  
2 the results indicate and what I have looked at here.

3 The figure itself shows a plot of the  
4 calculated concentration in rock fractures versus  
5 distance from the landfill for the Burlington Landfill  
6 after a period of 15 years for the contaminant I am  
7 referring to as benzene; that is benzene with the  
8 parameters that I have just described. This is a  
9 fairly easy figure so I will try and work through it  
10 slowly. There are a number of cases I have considered  
11 but at this point in time I would like to restrict my  
12 discussion to the case of a Darcy velocity of 0.7  
13 metres per annum.

14 On this overhead is summarized the  
15 results of six cases I examined for that particular  
16 Darcy velocity. The full details of the cases I  
17 considered is given in my Site F report in table 1  
18 which is on page 34 of Exhibit 440. I have simply  
19 summarized on the overhead a number of the more  
20 significant parameters that I am looking at at this  
21 point in time.

22 Case one corresponds to a fracture  
23 spacing of 1.2 metres and a fracture opening size of 30  
24 microns. Based on this particular Darcy velocity that  
25 gives you an average linearized groundwater velocity of  
about 28 kilometres a year, rather fast. In terms of a



1  
2 porosity it is 0.000025. That is a fracture porosity.  
3 I was interested just to see what one might expect in  
4 terms of benzene migration from the Burlington Landfill  
5 if one were to assume those parameters. The results of  
6 my analyses are shown by the curve for case one which I  
7 highlighted here in brown and to give you some  
8 perspective on what the numbers are, if we look on the  
9 left-hand side of the figure we see concentrations  
10 expressed in micrograms per litre. This is based on  
11 the initial concentration I assumed. On the right-hand  
12 side of the figure I have expressed the concentrations  
13 in a dimensionless form relative to my adjusted  
14 concentration beneath the landfill. So even though I  
15 assumed a certain concentration these are expressed in  
16 a quite general form and you can calculate what would  
17 happen for other initial concentrations.

18 I would like to focus our attention here  
19 on the actual numbers. Let us see what a situation  
20 like this might mean, would mean in terms of the  
21 concentration in the fractures about 25 metres  
22 downgrade into the landfill which is where  
23 approximately boreholes 24 and 12 are located. In fact  
24 I have indicated on this overhead the approximate  
25 locations of a number of the boreholes south of the  
Burlington Landfill. So here is the approximate



1  
2 location of boreholes 12 and 24. Borehole 15 in terms  
3 of lateral distance is about there (indicating).  
4 Boreholes 16, 13, 27 and 26. What one can see is that  
5 if these were realistic parameters then one would  
6 expect very high concentrations of benzene 25 metres  
7 from the landfill in the order of 110 micrograms per  
8 litre. Indeed, no concentration like this has been  
9 reported. Mr. Feenstra discussed the concentrations of  
10 organics and there is no indication of any significant  
11 benzene at borehole 24. The data that was discussed in  
12 his evidence indicates perhaps a trace of benzene but  
13 certainly less than one microgram per litre. So this  
14 does not seem to be very realistic.

15 Q. When you say "this" you are  
16 referring to case one?

17 A. Sorry, thank you, I am meaning  
18 case one. Case one does not seem to be very realistic.

19 So let us move on then and let us look  
20 at what happens perhaps if the fracture spacing was  
21 0.3. For a fracture spacing of 0.3 I looked at two  
22 different fracture opening sizes, again exactly the  
23 same total flow and if we look at two different  
24 fracture opening sizes we end up with two porosities.  
25 Case number two has a porosity of 0.0001 and case  
number three of 0.001. In terms of the groundwater



1  
2 velocity these imply groundwater velocities for case  
3 two of about seven kilometres a year and case three,  
4 about seven kilometres a year. I have summarized the  
5 results of both of those cases ...

6 DR. KINGHAM: For case three you meant  
7 700 metres per year?

8 DR. ROWE: I'm sorry, 700 metres per  
9 year. I have summarized the results of those two cases  
10 on the figure here by the dashed line and I have  
11 highlighted it in what one might call orange. We can  
12 see that there is no ...

13 MR. ESTRIN: Q. Dr. Rowe, just point to  
14 it.

15 DR. ROWE: A. We can see that for ...

16 Q. Some of us might call that yellow.

17 A. For those of you who call it  
18 yellow, it is yellow.

19 MR. HODGSON: Perception is all.

20 DR. ROWE: The curve is for cases two  
21 and three which look at the effect of an order of  
22 magnitude different in the porosity indicate no  
23 significant difference in the results. These numbers  
24 are not precisely the same but to all practical  
25 purposes they are. If we ask ourselves what  
concentration might we expect 25 metres downgradient of



1  
2 the landfill, we look at where the 25-metre distance  
3 intersects with that curve. We come up with a very  
4 high concentration of the order of about 90 micrograms  
5 per litre. Again, I would indicate that this is not at  
6 all consistent with what has been observed; that is no  
7 significant benzene migration. So we can see then that  
8 for a fracture spacing of 0.3 irrespective of which  
9 those porosities are looked at I get essentially the  
10 same result and it does not appear to be consistent, or  
11 is not consistent with what has been reported in these  
12 studies of the Burlington Landfill.

13 I then wanted to look further at the  
14 effect of fractured spacing so cases four, five and six  
15 look at the situation where the fracture spacing is  
16 0.05 metres and look at in this case three different  
17 fracture opening sizes. For case four it is five  
18 microns and that corresponds to a porosity of 0.0001  
19 for case four. For case five it is 50 microns and that  
20 is a porosity of 0.001. For case six it is 500 microns  
21 and that is a fracture spacing of 0.01. So here we  
22 have three orders of magnitude difference in the  
23 groundwater velocity corresponding to those different  
24 porosities. I have plotted the results for those three  
25 cases, I have indicated or highlighted them here in  
what I would call red. There is, as I pointed out



1  
2 before, a slight difference between the results. In  
3 this case I actually tried to plot it but it is very,  
4 very small. For all practical purposes the results for  
5 cases four, five and six are identical. This is  
6 indicating that the groundwater velocity or, if you  
7 like, the fracture opening size is not having a  
8 significant effect on the results. If we ask ourselves  
9 what concentration might we expect at borehole 24,  
10 about 25 metres from the landfill we would see a  
11 concentration of somewhere of the order of 60  
12 micrograms per litre. Again this does not seem to be  
13 -- this is not consistent with what has been reported  
14 and observed downgradient of the Burlington Landfill.

15 So, the conclusions that I would draw  
16 from this particular set of cases, that is cases one  
17 through six, is that on the time scale of 15 years we  
18 can see that the fracture spacing does have an effect  
19 but that irrespective of which fracture spacing we look  
20 at we have high concentrations of benzene that should  
21 have been readily observed 25 metres downgradient of  
22 the landfill.

23 The other point that I would indicate is  
24 that while fracture spacing is of some importance in  
25 this frame of reference the reason for that is 15 years  
is not a large time for diffusion to occur into the



1  
2 matrix of 0.3 metres spacing, although it is a fairly  
3 large time with respect to a fracture spacing of 0.5.  
4 We are seeing that local time scale that we discussed  
5 earlier makes itself apparent. So fracture spacing is  
6 of some importance at small times, i.e., 15 years in  
7 this case. The fracture opening size or the  
8 groundwater velocity, or the porosity, because they are  
9 all related doesn't have a significant effect.

10 Mr. Chairman, I am going to continue  
11 talking about this same figure 4 which is overhead 23  
12 in my report. I am actually going to put up another  
13 marked copy of it so we don't get too many coloured  
14 lines confused. This is essentially the same results  
15 except I have removed cases one through six simply for  
16 the sake of clarity.

17 MR. HODGSON: I wonder, Mr. Chairman, I  
18 am not sure that it mattered in these exhibits before  
19 but we are now getting into results. It seems to me we  
20 may want to refer to these various marked-up copies.  
21 Perhaps since the exhibit is marked as M-444, overhead  
22 23, that the first marked-up copy should be marked as  
23 an exhibit and can become M-444 OH-23A and this could  
24 be OH-23B. Would that be acceptable?

25 MR. LANCASTER: Yes, I'm glad you worked  
that out. So this one will be 23B and the one before



1 it will be 23A, OH-23A.

2 --- EXHIBIT NO. M-444-OH-23A: Calculated migration of  
3 benzene from the  
4 Burlington Landfill  
after 15 years

5 --- EXHIBIT NO. M-444- OH-23B: Calculated migration of  
6 benzene from the  
Burlington  
Landfill after 15 years

7 MR. HODGSON: I think also, although I  
8 would have to be sure, I would have to see what that  
9 last marked-up copy looked like. I'm not sure, did it  
10 differ from what I had? I don't think it did. I don't  
11 think we have in our books a photocopy then of this  
12 second one.

13 DR. ROWE: There may not be but the  
14 results are precisely the same. The results have not  
15 changed.

16 MR. HODGSON: I just wonder if  
17 Mr. Estrin can provide me with a marked -- of a  
18 photocopy of this one.

19 DR. KINGHAM: All you've done is delete  
20 the cases one, two and three on it?

21 DR. ROWE: I have deleted cases one  
22 through six just because it was getting a little  
23 crowded. I wanted to focus attention on curves that  
24 were somewhat less in doubt. So this is exactly the  
25 same figure 4 from my Site F report.



1 I want to talk about the situation where  
2 the Darcy velocity is 0.05 metres per annum; that is  
3 cases seven through nine. Here I am looking at, in  
4 case seven, a fracture spacing of 0.3 metres and a  
5 fracture opening size of 300 microns. That  
6 corresponds, Mr. Chairman, to a groundwater velocity of  
7 50 metres per annum and if we look at the results for  
8 seven you can perhaps see them here. They are shown by  
9 that dashed line. I'm sorry, those lines are so close  
10 there it is hard to distinguish them. The key point is  
11 that case seven is for a spacing of 0.3 metres and zero  
12 dispersivity and case nine is for the same spacing but  
13 showing a dispersivity of 2.5 metres. So I am looking  
14 here now at what effect a small amount of dispersivity  
15 might have on the results. What we can see is that if  
16 the fracture spacing is of the order of 0.3 metres and  
17 dispersivity is zero we would not be expecting benzene  
18 to be detected 25 metres downgradient of the landfill.  
19 If it were the same fracture spacing but there were  
20 dispersivity of 2.5 metres then one might just detect a  
21 very trace amount 25 metres downgradient of the  
22 landfill. So that for a fracture spacing of 0.3 it is  
23 arguable as to whether benzene would be expected. The  
24 probability is that you would not detect for this Darcy  
25 velocity.



1                   If we look at case eight, this is a  
2 fracture spacing of 0.05. Case eight is shown by this  
3 curve here. If the fracture spacing were 0.05 and the  
4 Darcy velocity were also 0.05 then one certainly would  
5 not expect to find benzene 25 metres downgradient of  
6 the landfill. When I say you wouldn't expect to find  
7 it, you wouldn't expect to find it at levels greater  
8 than one microgram per litre. Probably if it was there  
9 at all it would be substantially less.

10                   DR. KINGHAM: Do we understand that for  
11 all of the statements you have made in the last half  
12 hour, that is in 15 years?

13                   DR. ROWE: That is in 15 years, that is  
14 correct.

15                   The next set of results that I would  
16 like to look at are referred to as cases 26 and 27.  
17 This is for a Darcy velocity of 0.125 metres per annum.  
18 Case 26 is for a fracture spacing of 0.3 metres, a  
19 fracture opening size of 300 microns. This corresponds  
20 to a groundwater velocity of 125 metres per annum and  
21 both of the cases, 26 and 27, use the dispersivity of  
22 2.5 metres. If the fracture space were 0.3 of a metre  
23 and the groundwater -- the Darcy velocity were 0.125  
24 then one would expect under those circumstances to find  
25 benzene at borehole 24 downgradient of the landfill at



1 a concentration of the order of 17 micrograms per  
2 litre. If the spacing were 0.05 then that corresponds  
3 to curve 27 which is a conglomeration here. One would  
4 not expect to find benzene at the one microgram level  
5 24 metres downgradient of the landfill.

6 So based on -- if one just looks at this  
7 information on its own, based on the field observations  
8 -- I will supplement this with other information -- one  
9 would certainly not expect the Darcy velocity to be  
10 0.7 metres per annum. Although it is possible it is  
11 unlikely that it is as high as 0.125 metres. If it  
12 were 0.125 metres you would need a very close fracture  
13 spacing in order that it not be found.

14 The most probable situation of the cases  
15 considered is 0.05 metres per annum. This happens to  
16 correspond to what Dr. Charlesworth indicated is likely  
17 to be the Darcy velocity. This corresponds to the  
18 gradient and hydraulic conductivity that he quoted.  
19 Using these parameters alone it is possible that a very  
20 small amount would be detected if one has a  
21 dispersivity in the order of 2.5 metres. The  
22 likelihood is that you would not detect benzene as  
23 indeed is the case downgradient of Burlington Landfill  
24 after 15 years migration.

25 Now, that essentially summarizes my



1 results with respect to the migration of benzene.

2 DR. KINGHAM: Can you just tell us  
3 before you take that down which you think is the best  
4 model or is that going to come out later?

5 DR. ROWE: Yes, I can certainly give you  
6 a preview. I think the most likely situation is of the  
7 order of 0.05. It could -- one could develop a  
8 scenario where it is up to 0.125 but I don't think that  
9 is likely.

10 DR. KINGHAM: Which would correspond to  
11 which case?

12 DR. ROWE: Zero point zero five is cases  
13 seven, eight and nine. I think the most likely  
14 situation is for a Darcy velocity in the order of 0.05  
15 metres per annum given the range of fracture spacings  
16 that have been reported.

17 MR. ESTRIN: Q. I have understood what  
18 you've done here, you've looked at a number of cases  
19 and plotted the graphs that arise from those results,  
20 compared it to what observations we have at the  
21 distance that you have indicated. So, which comes --  
22 which is the input and which is the output here in  
23 terms of the cases versus the Darcy velocity? Is it  
24 the Darcy velocity first or the reverse?

25 DR. ROWE: A. Yes, Mr. Chairman, the



1 Darcy velocity is I would say the key input parameter.  
2 It is the most important of the parameters. The next  
3 most important in the case of the Burlington Landfill  
4 is the fracture spacing. So, I looked at what the  
5 effect of fracture spacing might be and those are the  
6 two primary input parameters. Now, in addition to  
7 that, one can take a fracture-opening size and as a  
8 result of those three parameters one deduces what the  
9 groundwater velocity is going to be. It is not an  
10 independent quantity. It is fixed by that Darcy  
11 velocity, fracture spacing and the fracture-opening  
12 size.

13 Q. In terms of answering the question  
14 of which of the Darcy velocities is most likely, you  
15 look at the cases, the results of those cases?

16 A. I looked at the results of all of  
17 the cases here in coming to my conclusion as to which  
18 of the Darcy velocities seems to be the most likely.  
19 Based on these results, I would conclude that this  
20 Darcy velocity seems to be the most likely. When I say  
21 "this", this is a Darcy velocity of 0.05 metres per  
22 annum.

23 Q. Then you did the same kind of  
24 thing I take it with respect to chloride?

25 A. Yes, Mr. Chairman, I repeated



1 essentially this same exercise looking at chloride and  
2 I would refer to overhead 24 in my witness statement  
3 which is in fact a reproduction of figure 5 from my  
4 Site F report. This overhead again summarizes on the  
5 left-hand side the concentration in the fractures and  
6 on the base axis we have distance from the landfill.  
7 On the right-hand side we have concentrations expressed  
8 again in dimensionless form. This is similar to the  
9 previous result except it is for chloride.

10 I should point out here, Mr. Chairman,  
11 that I am using chloride as an example of a  
12 conservative species. In fact, as has been indicated  
13 in earlier evidence chloride is in higher  
14 concentrations in the rock than it is in the landfill.  
15 So we don't expect chloride itself to be a contaminant  
16 causing problems within the rock. Indeed, if one were  
17 to consider chloride as that specific ion, one may have  
18 chloride diffusing out of the matrix into the fractures  
19 because it is at higher concentrations in the rock  
20 itself but that is not what I am concerned about here.  
21 What I am concerned about here is just looking at  
22 chloride in a generic sense as being representative of  
23 a highly-mobile, non-reactive contaminant. So, this is  
24 a generic chloride, if you like, simply an example of a  
25 highly-mobile, non-reactive contaminant.



1 I again considered three different Darcy  
2 velocities. Cases 10 and 11 correspond to a Darcy  
3 velocity of 0.7 metres per annum. Case 10 is  
4 specifically for a fracture spacing of 0.3 metres.  
5 Case 11 for a fracture spacing of 0.05. The results of  
6 those two cases are as shown on the figure and I have  
7 highlighted in green. Case 10 is the wider fracture  
8 spacing and you can see here that the concentration  
9 decreases fairly gradually with distance from the  
10 landfill and we got quite significant levels even 350  
11 metres away. At a closer fracture spacing we see the  
12 curve is much sharper. This in fact is the point I was  
13 trying to draw out this morning in my explanation of  
14 fracture spacing at smaller times is that if you have a  
15 close spacing, what you are likely to get is higher  
16 concentrations at locations close to your landfill but  
17 it gives a much sharper profile, it restricts how far  
18 the contaminant is moving. Because at the closer  
19 spacing there is more potential for the contaminant, it  
20 is easier for the contaminant to diffuse into the  
21 matrix of the rock. It has less distance to travel and  
22 therefore it gives a much sharper curve in terms of the  
23 concentration profile at small times. I emphasize 15  
24 years is a small time, particularly with respect to a  
25 fracture-spacing range of five to 30 centimetres that



1 we are dealing with.

2                               Irrespective of the uncertainty as to  
3 the fracture spacing the net result is that one would  
4 expect very, very high concentrations of any  
5 conservative-type contaminants to be detectable 25  
6 metres from the landfill if the Darcy velocity were 0.7  
7 metres. This does not appear to be the case based on  
8 the evidence that is available, although clearly the  
9 evidence for conservative contaminants is not as clear  
10 as it is for the organic contaminants we have  
11 discussed.

12                           The second group of cases I would like  
13 to discuss are for the Darcy velocity of 0.05 metres,  
14 once again I considered two fracture spacings and this  
15 case corresponds to a groundwater velocity of about 50  
16 metres per annum. This case 12 is for a fracture  
17 spacing of 0.3 metres and is shown here in purple and  
18 case 14 is for a fracture spacing of five centimetres  
19 or 0.05 metres. It is shown in red and one can see  
20 that if the Darcy velocity were 0.05 metres per annum  
21 then one might find low levels of conservative-type  
22 contaminants at borehole 24 up to perhaps about three  
23 per cent of the source value. That is what we would  
24 expect for the wider fracture spacing. If the fracture  
25 spacing were closer then one would not expect to find



1 even conservative contaminants 25 metres from the  
2 landfill. This again appears to be consistent with the  
3 evidence that is available from the plume delineation  
4 studies.

5 If we look at the third situation which  
6 is a Darcy velocity of 0.125 metres, again I looked at  
7 two different fracture spacings and this corresponds to  
8 groundwater velocities of about 125 metres per annum.  
9 If the velocity, the Darcy velocity were this high,  
10 then 25 metres from the landfill we would expect  
11 concentrations in this range shown here. That is a  
12 range between about 30 and 45 per cent of what the  
13 contaminant value was within the landfill. There does  
14 not appear to be any strong evidence that the  
15 conservative-type contaminants have moved at this level  
16 24, to borehole 24 or borehole 12. As I say, the  
17 evidence with respect to conservative-type contaminants  
18 is clouded by the poor quality of the groundwater and  
19 while I would concede that it is possible that the  
20 Darcy velocity could be as high as 0.125 I think that  
21 is unlikely and the probability is that it is -- the  
22 likelihood is that it is more in the order of 0.05  
23 metres per annum. That is based on looking at the  
24 information with respect to both conservative-type  
25 contaminants as problematic as it may be and the much



1 clearer evidence with respect to organics.

2 MR. ESTRIN: Mr. Chairman, we are going  
3 to be some little more time with this witness.  
4 Certainly we can't finish before 5:00 o'clock. Perhaps  
5 I could just ask Dr. Charlesworth, Dr. Rowe, with  
6 regard to -- there is another overhead with regard to  
7 chlorides if you can tell us whether you think it would  
8 be appropriate, just to finish off this discussion with  
9 No. 25. I don't know if you were intending to refer to  
10 that. Would it be relevant to refer to this now or we  
11 can continue with that tomorrow morning?

12 DR. ROWE: My overhead 25? Well, I am  
13 at -- it logically follows from the one I am talking  
14 about but I will be happy to talk about it tomorrow.  
15 It logically follows from five and then I will be  
16 moving on to a different subject.

17 MR. ESTRIN: Mr. Chairman, what ...

18 MR. LANCASTER: If you want to go on  
19 with 25 ...

20 DR. ROWE: Twenty-five is essentially a  
21 blow-up of some of the results that we saw previously  
22 plus two additional results. Again we are dealing with  
23 chloride after 15 years. It is the same type of plot,  
24 the concentration in the fractures versus distance from  
25 the landfill. Here I have changed the scale to make it



1 a little easier to read because in the previous case it  
2 was a fairly tight scale. I have shown here the  
3 results for cases 12 and 13 which are both at a  
4 fracture spacing of 0.3 metres for two different  
5 dispersivities. So here I am illustrating what is the  
6 effect of dispersivity because this is a number we  
7 don't know the precise value of. It is another factor  
8 to examine. All of these results are for a Darcy  
9 velocity of 0.05 metres per annum. So 12 and 13  
10 indicate -- there is curve 13 and curve 12 is shown  
11 there. I have cross-hatched the region in between them  
12 to indicate the potential effect of this range of  
13 difference in dispersivity. I might point out that the  
14 dispersivity of 2.5 metres is ten per cent of the  
15 travel distance of 25 metres that I am interested in.  
16 If the fracture spacing were 0.3 metres then one would  
17 expect conservative contaminants to have travelled to  
18 borehole 24 in 15 years at levels ranging between three  
19 and ten per cent of the original value in the landfill.  
20 If the fracture spacing were 0.05 then that same range  
21 in dispersivity from zero to 2.5 is indicated by the  
22 cross-hatched yellow area. One might just find very  
23 low levels of conservative contaminant at 25 metres.  
24 So this is a bit more evidence that one draws together  
25 in trying to form a feeling or an opinion I should say,



1 trying to form an opinion as to what is the most likely  
2 Darcy velocity and what is -- what I consider to be the  
3 worst case velocity. The most likely velocity is of  
4 the order of 0.05 metres per annum and I do not, on the  
5 evidence available, believe that it could be any worse  
6 than 0.125 metres per annum.

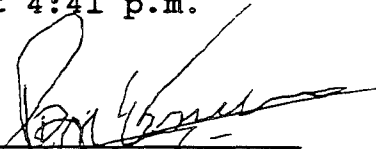
7 MR. ESTRIN: That may be the appropriate  
8 place to stop for the evening.

9 MR. LANCASTER: We will adjourn until  
10 9:30 tomorrow morning.

11 --- Adjournment at 4:41 p.m.

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P. D. McQueen

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