

Critical Issues Conference On In-Facepiece Sampling

PART 2

International Society For Respiratory Protection and National Institute For Occupational Safety and Health

- PROCEEDINGS -

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All the following information and results on tests will be for inhalation and exhalation cycles only.

What I did here was, we put another respirator, waxed onto the manikin with great care. We made sure that the leak lines were exactly the same and, of course, the diameters were the same so that we would expect that each single leak site would have the same amount of leakage and that is basically what it shows. When we were liking at single, double and triple link sequences the point of the measurement doesn't make any difference. When we are at probe one location, with two and three closed, we have a sampling rate of about 167 cc per minute. As you might expect, if you double that amount of leakage, you have about twice that volume. Because of the pressure drop it doesn't measure out to be quite the same. And, of course, if all three of them are leaking, then you might expect three times that amount. And those values came out very close.

All of the rest of the information given in this presentation will be using those defined leak rates. The first thing we did was, after fitting the manikin, getting the respirator waxed onto the manikin, was to look at the single leak sequence. Here again the variability is very high. It is so high that it covers a span that is about 1500 percent. That is going from the extreme low fit factor. In other words, the fit factors underestimated on the extreme 42 percent lower than real value and overestimated as much as 1400 percent.

It is interesting also to note that when you take the average of all the factors that it drops down to about 100 percent relative standard deviation.

After the singles come the doubles. Looking at combinations of two leaks at one time - very much the same story. Here again this region always seems to be heavy in the extreme values. What it is I don't really know; it is just peculiar to our test setup; perhaps it is; perhaps it isn't. Here again the underestimation is 33 percent; overestimation is about 700 percent.

Looking at all three leaks simultaneously -- what has happened to all the variability? It seems to be gone now. This is very close agreement, a relative standard deviation of 19 percent. Maybe this

is kind of like the optimum conditions to get the results to agree with the flask concentration. Maybe one leak is helping the other mix on the inside of the respirator, inside the cavity of the respirator.

So if that is true, then maybe if we took a portable pump and attached the inlet and outlet lines to some needles and put the needles inside the respirator, where we have a 16 gauge needles being used for the pickup and a 16 gauge needle being used to return the flow, maybe this additional mixing inside the cavity will make everything homogeneous.

Well, when we did that we did this. Here again the variability is extremely high. The bottom line is it is 2000 percent. That is a big deviation. Like I keep pointing out, it is interesting when you take the average of all these numbers you get back to the 100 percent region.

What I did was since we are using the same respirator on all our testing now, it is easy to go back and retest some earlier results, and what we did was to look at the single leaks with and without inside mixing. And there is some differences but one pretty well follows the other at the single leak condition, anyway.

Looking at all three leaks leaking simultaneously again, which is kind of our best result, best agreement, no mixing again; mixing across left to

right, which gave almost the same results; and then all we did was just change the angle of the return nozzle and if this is pointed in a downward direction we can cause probe one now to give a different reading and probe two does also, so does probe three. We changed the angle of the mixing again in an upward direction this time and the numbers change again.

Well, when you get through doing a lot of tests you have to come up with some conclusions and I was forced to do that.

I will go through them one at a time. Respirator probe location and leak location have a significant effect on the measured value of a protection factor or a fit factor.

Concentration gradients appear to exist within the respirator cavity using a particular challenge. I might add concentration gradient bands also appeared to exist with vapor challenge.

Inside facepiece concentration variability appears larger than previously expected.

Concentration gradients appear to exist in both rubber facepiece and disposable respirators.

Variability exists whether or not the test apparatus incorporates a simulated exhalation, though the results may not be the same.

Averaging the results of several quantitative fit tests may still have meaning. The more samples you take, the better chance you have of approaching a mean.

At this time the data presented are considered to be preliminary and are insufficient to statistically treat.

It is possible that the facial features of an individual would affect the optimum probe placement. I think that is very logical. If one is true, then certainly eight is true. All the work reported here was done on a

single face form, from a single face form.

And last, some recommendations and, as usual, more work needs to be done and we need to work at developing a technique to determine accurate fit factors. It is also my recommendation that we strongly consider qualitative fit testing as an alternative. Thank you.

Mr. Johnson: Just to start out so I understand your breathing cycle, you exhale fresh air. Is that correct? Back to the respirator?

Mr. Mullins: Yes.

Mr. Johnson: So you did not take the sample that came in and exhale it back out?

Mr. Mullins: That is correct. We did not.

Mr. Johnson: Okay. I saw no data to give us a background when you just put the mask on and there were no leaks introduced or anything. Did you run backgrounds -

Mr. Mullins: Oh yes. That is actually the purpose of using the 2.5 micron size particle, to prevent the filter medium from being penetrated by smaller particles. So there was zero background.

Mr. Johnson: It just seems that you must do a lot of cleaning because if that flask was used over and over again I would be concerned about resuspension and loading it up, looking at the number of tests you ran.

Mr. Mullins: The flask seemed to respond very quickly. There is part of the dynamic flow going through there. You know, it is sweeping out every time at 40 liters a minute.

Mr. Wilmes: Just a quick comment - this is Don Wilmes - remember, aerosol is DOP, which is a liquid and liquid aerosols are rarely re-entrained. They go out to surface and so you really don't have

that problem.

Mr. Mullins: That is correct, yes. Once they impact on the surface, they stay there.

Mr. Lotito: Frank Lotito, Mine Safety Appliances. You presented some data indicating that the flask concentration was dependent upon the incident concentration -

Mr. Mullins: Challenge - challenge concentration.

Mr. Lotito: Right. In the process of putting the mask in place - well, first you have an explanation as to why the flask concentration is concentration dependent. I assume the geometry is the same all the time.

Mr. Mullins: Yes. I guess I really don't have an explanation at this time, other than it seemed like the relationship was quite a linear relationship and, basically, we were losing ten particles per channel each time low concentrations were transported through the system.

Mr. Lotito: Does any type of theory involving the transport of small particles from here to there explain the susceptibility - can anyone comment on that? - of the challenge in one location to be concentration dependent? If the geometry remains the same?

Ms. Iverson: Not for this size particle.

Mr. Brennan: I would like to make a comment on that subject. This is Bob Brennan, Scott. First I would like to ask which type of back scatter photometer you were using.

Mr. Mullins: It was a Comet, series 135 I think.

Mr. Brennan: Whenever in the past that I have placed a back scatter photometer of that type that close to a breathing machine, I have found it is sensitive to the pressure wave from the breathing machine and, in

general, when the breathing machine is inhaling I have noticed a tendency to under-read on the back scatter photometer, which seems to correlate with the static pressure just outside the back scatter photometer. I wonder if yourself or anybody else in the room has ever done any work in that area.

Mr. Mullins: I haven't myself. I don't think we had that particular problem with this system because all the precision information that was generated was during rate of machine cycling.

Mr. Brennan: Sir, did you ever track a full pulse of the breathing machine, that is, breathe in and out with the aerosol and look at the readout from the back scatter photometer as you pulsed in and out when you are mounted that close?

You were very closely coupled to the breathing machine.

Mr. Mullins: Yes, I didn't notice anything happening that was unusual at all.

Mr. Brennan: You did try it?

Mr. Mullins: Not necessarily like that but I think that it was incorporated.

Mr. Brennan: I would suggest you go back and look at that. I would like somebody to verify what we have seen.

Mr. Lotito: Going back to my question in regards to the flask concentration being dependent upon a concentration upstream of the flask--

Mr. Mullins: Yes?

Mr. Lotito: -- in the process of placing a filter - a respirator, excuse me, across the face form, probing it in various locations, including leaks, if you continue to look at the flask concentration and try to make some inference as to the probe is saying something, the flask is saying something, how do you really know what the flask is saying since the concentration is unknown in the

mask?

Mr. Mullins: I guess one of the ways to approach that is to know what your leak rate is. If you know what the upstream concentration is, then you should know how much mass is being transported inside the respirator. And we were able to account for a little bit over 50 percent of this. In other words, there was a 50 percent particle loss during the transportation, which I don't think is really unusually for liquid particles -

Mr. Lotito: You had a 50 percent loss through your induced leak?

Mr. Mullins: I think there could have been.

Mr. Lotito: Okay. And on the downstream side of the induced leak the concentration was so many particles?

Mr. Mullins: If you wanted to extend it to that, you could, yes.

Mr. Lotito: Thank you.

Mr. Mintz: Al Mintz, Moldex. I take it you use one configuration of the mask. Did you do any studies in other configurations prior to this to see if you would get the same figures or comparisons?

Mr. Mullins: No, we didn't have time to do it. It is certainly on the agenda.

Mr. Mintz: Thank you.

Mr. Wolfred: Rod Wolfred. I am with the Painters Union. On your recommendations I noted that, of course, you wanted to study more the quantitative fit test -

Mr. Mullins: Yes.

Mr. Wolfred: -- and of course, from what we have seen today that seems very applicable. In regard to your desire to substitute qualitative fit testing though, I am somewhat baffled because isn't it a fact that the qualitative evaluations you have done have been based upon the quantitative methods that we

have now seen refuted to some degree?

Mr. Mullins: Perhaps if I had been in the business long enough that would be true. I have just recently started studying particles and I don't know exactly how quantitative and qualitative fitting correlates.

Mr. Wolfred: I am wondering about your recommendation to substitute the one for the other. That was my point.

Mr. Mullins: Yes. The recommendation is that it seems like that if jet streaming should occur that it would eventually make it into the mouth and since your tongue can detect something like saccharine or an irritant smoke, or something like that, then you would respond to it and perhaps that could be a better test.

Mr. Billings: Billings, from Hopkins. Am I hearing that you are saying the same thing that Rod is saying, that it really doesn't matter whether I do quantitative fit testing or quantitative fit testing, I don't have any better estimate of the actual fit of the respirator? That is sort of what I am hearing here, that you have several orders of magnitude variability in the quantitative data and I think you would agree there are probably several orders of magnitude in subjective evaluations of fit as well. So either method gives you about the same.

Mr. Mullins: Yes. I can't answer your question because I haven't made up my mind.

Mr. Wolfred: In response to Dr. Billings' query in regard to the issue, I guess my feeling would be that the qualitative work that has been done seems to be based on detection of the individuals of concentrations that have been measured by quantitative methods. So, consequently, we cannot be sure then that the people

are actually sampling, that they are actually tasting the samples at the concentrations that have been projected. So I would say, in essence, that I would not be saying the same thing that you are; I would be saying that qualitative has been cast completely into doubt in that regard to this until verification of the quantitative methods by some other means in regard to that qualitative method being determined. So I would be saying something a little different than you.

Mr. Wilmes: Any more questions?

Actually, we have diverted a little bit into tomorrow's discussions but if there are more questions on this presentation at all?

Mr. Raven: Peter Raven, at TCOM. I suppose I am a little concerned that what we are worried about is trying to quantify fit when what we really should be worried about is what is the human going to be setting. And therefore your probe placement, it doesn't matter where it is, tells me what the human is getting and then you can make some decisions. And I think you are worrying too much about getting me a fit number and what we should say is, hey, what is the guy really breathing? And that is really what I would like to see you going for, rather than, hey, give me a number on whether a respirator is fitting or not.

Mr. Wilmes: I see they are bringing some soft drinks in. I am sure we are all a little low on carbohydrates right now — so let's reconvene at about 3:15.

Mr. Wilmes: Could we be seated and begin? The final presentation for today will be given by Jim Johnson, from Lawrence Livermore National Labs, after which, if there are any further questions on any of the presentations made up to this point, we will entertain those. Jim?

Mr. Johnson: Well, it has been an interesting day for me. I have heard some review of some points that were presented earlier but Warren and some other supporting evidence that might make you think, if you are new to the respirator field, why am I putting all that money into those funny things for? They are uncomfortable and people really don't like to wear them anyway.

I would like to provide a little insight from an industrial hygienist point of view first and then a research -- whatever you want to call it -- respirator or some kind of research perspective, second.

Okay, I put this slide in to remind me that we received an announcement on 11/30/84 about this - well, it was dated 11/30 and I think we got it around December 5th and we really hadn't done any thinking about the subject but felt that a practical interpretation should be made so that within a month, along with Christmas and New Year's, we have tried to put this study together, trying to give you a little more perspective on the subject.

Now, it has been a concerted effort by my group at the laboratory and also several long conversations with Ben Lien from OSHA, trying to provide me a mentor's position on this topic.

Now, if we look at the subject that Warren and everyone else has brought in, it kind of boils down to really a key question that I think we have to ask -- is there significant variation in the aerosol concentration in the nose-mouth sampling area during normal breathing when wearing a respirator which has a leak? To me that is kind of the bottom line and something that needs to be looked

at further.

Now, when you are set into this question you have to say, well, what am I going to look at? So we had to first choose what type of respirator we were going to examine.

Now, when you think about that you can figure, well, I will look at the half mask, the full face mask, do I want it air purifying, air supplying? Well, we have the powered air purifier question and then the self-contained breathing apparatus.

Really our practice at the laboratory, and I think throughout a lot of industry, is quantitative fit testing of half masks by the functioning field industrial hygienist is not done. I mean, you use an irritant smoke test. There is data that supports -- you get a protection factor of ten. So an investigation into that area seemed futile for us right now to evaluate when we want to really see if there is a significant problem. So we chose the full face respirator to take a look at and see if there was a problem there.

Now, back to our question, to my surprise today, nobody used just plain old oil-mist laskin (phonetic) generated aerosol. The British have used salt for a long time but that is the way the data was generated that we are comparing to if you go back to Los Alamos data. So our choice of test aerosol was an oil mist and because of the toxicity concern we ended up with PEG, polyethylene glycol, molecular weight 400. That is what we used as our test aerosol. We used a photometer, which again is your normal detection device, and most of the quantitative fit data that is in the literature.

We thought we would like to use a breathing machine. We used a breathing machine on the full cycle, rather than on the negative cycle. We have done a little constant negative

flow study just to see if the streamlining that was observed is really something that we could reproduce. We had a big problem introducing a leak.

Now, I wanted to make sure I understood how Warren's leak was put in on his study, and it is an eighth inch tube. That is your point source. Now, you have to think about that as far as a normal respirator leak. That is very highly unlikely, to find that big an area exposed.

We fiddled around with a hypodermic syringe under the sealing surface and we ended up with using one of the sampling ports in the facepiece to reproducibly introduce a leak into the respirator and I will show you that a little later. But I think it is a point that could produce a lot of variability in the studies. If you can't reproducibly provide a leak into the respirator, how do you know what measure isn't the leak?

Then how and where do you measure the test agent? That is certainly another question that needs to be addressed.

Now, Warren was out at the lab and presented a little more abbreviated version of what we heard today and we certainly didn't have the audiovisual representation, which provided a lot of insight for me. But two questions that people who heard it and myself generated from what we heard from Warren were, number one, is air flow within a full facepiece laminar? It is certainly a very critical question. Question number two, from Warren's work we might think that there are significant differences from probe location within a facepiece. And I think that has been supported today from some other data. So those were the two questions that we wanted to quickly try and evaluate in the short period of time that we had.

So what we did initially was we put a videotape together. We figured a picture would be worth a thousand words. And what we wanted to do was look at Warren's conditions of a 16 gauge syringe needle and a smoke tube, with which we had problems, under negative pressure. Then we wanted to run our breathing machine under purely negative cycle breathing. Then we wanted to use the full breathing cycle and, in our case, we discharge what is put into the machine back into the respirator, rather than bringing in fresh air.

We used a 14 gauge needle and we had to end up using titanium tetrachloride to get a little better source of HCl, rather than the standard chloride tubes.

Now what I would like to do, Warren, if you want to flip on the video -- and I have to narrate. We didn't have time to put music and a lot of fancy things to this --

Okay, now remember what we did here was we were looking at constant negative flow and what I want to try and do -- remember, our question at hand is, is the flow within the facepiece laminar or turbulent? That is what these first series of tests are meant to try and demonstrate.

Note the rotometer on the side which will give an indication of flowrate. We will start at ten liters a minute. Constant negative flow. There is a little syringe on the left that we introduce the test aerosol, and you will see at ten liters a minute there is some semblance of a streamline going in there. It is similar to what Warren was able to generate over here with his test apparatus. Remember, this is one of our techs doing the photography.

But even here, you see that it is

not a straight line. There is a significant amount of mixing in the nasal-mouth area.

Now what we do, we come back, we up the flow. We will up the flow to 20 liters a minute. Note the puffing effecting that you start to see already in the facepiece. So if there was laminar, we are starting now to go to some mixing, some turbulent type of flow in that facepiece.

We will go up to 30 liters a minute shortly. Again look up on the top of the nose and if you see how it is swirling around, up around the eyes even, on that shot.

Then the last negative flowrate will be 40 liters a minute. There is our technician checking things out. Again, it is moving through that respirator facepiece very quickly at 40 liters a minute, as you can see. You will see some puffs around the facepiece.

Now we are going to look at the breathing machine inhalation only, 622 cam, varying the rpm on it. Again the rotometer will give you an idea of when we are inhaling and when we are at rest in the facepiece.

Note again how it diffuses very nicely in that facepiece. This is inhalation only. Now if you watch the speed of the cam, it will be picked up. I didn't bring that along but what we do is run the rate of the breathing machine up, try and take up, I think, to around 40 liters a minute, as I recall. You will see by just the puffs, the inhalation rate picking up.

Again note how you see a lot of the mixing in that full facepiece. I think this puts us probably to the highest breathing rate. It is a fairly turbulent region in around the nose-mouth area. Remember, we are breathing through the mouth on this manikin.

Now we are going to go to cyclic breathing and we are going to look at

the MSA mask first. Then we are going to go to the Survivair. And this will give you a shot, using a Magnahelix to show the positive-negative action of the breathing machine.

Now, the reason we are using two different facepieces is because you heard a little discussion about dead space. Now, at our facilities we don't use nose cups in our full face masks on a regular basis. We use the MSA and the Survivair, the Survivair having probably one of the largest dead spaces of full face masks in the industry right now; MSA, one of the smallest.

Note on the exhalation how you will see a very fine, well-mixed aerosol being discharged out of the breathing machine.

Again we will vary the room a little bit just to show how it will influence the mixing. No semblance of a streamlining. I hope this is the last one.

Now what we will do is look at the Survivair. Remember, we have changed the dead space on the facepiece. This one is more visual too because of the size of the lens. The continued problem with the needle plugging - it was not an easy filming sequence hereto run.

Note, you can see when it becomes at rest in there and there is a little bit of just kind of quiet mixing before it is drawn in or blown out.

Now, remember as you look at this that the normal sampling area is right under the nose usually. Most of the data that we have been thinking about in full faces that has been done, it is usually in that nasal-mouth area where the probes have been put over the years.

It would have been a lot better if I had, had music and a little bit of up and down to up the pace for you but

we just couldn't hack that. That will be all, if you want to shut that off. Thank goodness, right? Okay, if I could have the slide projector back on, please?

Okay, what did we really draw from this very simple experiment, of which there is certainly some criticism, but I think also a reasonable conclusion that airflow in a full face respirator is turbulent. Therefore we can expect reasonable mixing on a complete breathing cycle, especially in the nose-mouth area. And the smaller the dead space in the respirator, the better you are going to find the mixing is what we felt was a preliminary kind of a decision from the data that we had.

Let's ask ourselves then the second question which we were interested in pursuing - is there significant differences with reference to sample probe location? Now, I think the biggest thing I want to emphasize is that normal sample probe location has been in the nose-mouth area for anybody who wanted to really measure quantitative fit. So I am just going to stress that. The data that has been generated throughout the years was done with sampling in that general area.

Now what I would like to show you is some of the equipment that we put together to try and do this second phase of the study.

What we set up was in our man test chamber, which is the aerosol chamber. We put a manikin on a cart. You can see the mask void shown there. Airflow would be in through a set of HEPA filters if we follow the flow. We have a source of aerosol, it goes in through the HEPA filters or through a leak. Then we come into the mask void. It flows in through the manikin tubing and then we go

through an inhalation tubing, inlet valve, and then we have a common breathing machine valve, some copper tubing to our breathing machine. Then we ex-hale back through some common tubing areas, an outlet valve, an exhalation tube, over to our manikin tubing, then to the mask void and then out.

So it is a cyclic phenomenon and it is meant to simulate the way a man wears the respirator. And I think that is another important point that we all have to keep in mind when we design our experiments -- are we testing the equipment as it is used? And the question that ended up the preceding session, how much really gets into the lungs? That is the bottom line for us and I think that was a very good point, well made.

Now, just to let you visualize the very tight area, this is a breathing machine. I will show you a little closer shot of that. Here is the sampling line that we used to determine essentially what the real leak rate was. What was in the breathing machine? And that is where we took that point. Then you can see on the full face respirator that we had various probe locations that we could sample and see what variations we found.

Just to show you our breathing machine, this is an older unit but it works very well. The key point that I wanted to make sure of is that we were taking our sample out on the exhalation cycle in this tubing here after it had gone into the cylinder and was being discharged. We were able to control the rpm and read that out also.

Now, what I wanted to show you is how we came up with a solution to the sampling probe where you would like to vary the depth into the respirator. What we did was simply take a commonly available Swedge-

lok fitting that you see right here. We had the end cut off, like you see here. Then we had the stop that is inside the tubing drilled out so that it would take a quarter inch ID tubing and we could slide it then in and out and make our seal lock with this type of arrangement here, which is similar to what you do on your commodes or sinks when you have problems at home and you wonder why you can't reuse that piece of tubing as you actually cinch down a furl on it. We found this to be a very successful variable probe depth arrangement.

Now, another close up view -- we used stainless tubing, quarter inch ID, very thin wall -- I have forgotten what it is. And here is the furl that goes on with the tubing and a little centering ring behind it. When you tighten this nut down this actually gouges into the tubing a small amount and holds it in place so that you can remove the tube and reuse it and get the same length of insertion then.

You can see that we had to also have this nut shaved down a little bit on a mill to make sure that we kept interior dimension as small as possible.

Again the system taken apart -- we put a nylon washer on the inside of the face-piece to make sure that we didn't crack it and this was the actual setup that was used to take our samples out of the mask.

Here is a half mask. We pondered the whole business of whether we should be looking at half masks. As I said, as we thought about it, we said, well, we really, at this point, are not interested because we don't quantitatively fit half masks. But it can be introduced nicely into the MSA combo to get an idea of the way we would pinch off the tubing, and then we had quick disconnects when we wanted to sample one of the three points.

Here is a Survivair, the same kind of

a setup. Note the tubing.

And then on the inside of the Survivair you can see that we probably were in about a quarter of the inch. That is the way the threads forced us on that. So all our data would be at least a quarter of an inch into the respirator cavity.

Now, here is the fullface lens from a Survivair and we put on five sampling points, this being number one, two, three, four and five. Now remember that these two represent to me the key area where sampling was done by anybody who was concerned about measuring the performance of the respirator.

An inside shot so that you can see that we did attempt to do a little milling down of the pieces. But if you have somebody who is skilled - notice there are no cracks. I look at a lot of respirator lenses and you will see a lot of little lines coming out and that always worries me, especially if I see silastic spread on. You don't have to have that if you are careful and people put them together right.

Okay, now here is the apparatus in place. And note the manikin head. Now, here is our leak, at least our first attempt at a leak. And that is why I say leaks to me worry me in this whole area right now of reproducibility. But that is what we did in the first place. This is a number 14 syringe, a good sized syringe. And you can see that it gets pretty busy as far as the facepiece goes. But we did take various samples around the respirator.

A little more close-up - excuse me, it is a number 13. It is a number 13 syringe. And we actually had to put a little bit of putty - we call it Aquaputty. You can't run an experiment without tape and putty. So to make sure that we got as low as possible background, in other

words, sealing all our leaks off when we look at that breathing machine number, we would go in and work on our manikin head to try and reduce that, and this was the point where we found some leaks.

So now, this is really where we want to ask the question - I want to put this back in so that we are all back to speed on what we are trying to consider -- is there significant difference with reference to sample probe location?

Okay, this chart gives some data that we put together. Now, the readout here is the photometer reading. We didn't do any conversations at this point. I just wanted to give you some raw data to look at output. Note here at the bottom, you can get your reference to sampling probe location. Needless to say, I have covered what I think are some important areas.

Now, the difference between sample number one and sample number two is that the mask completely taken off the manikin head, looked over, redone and we were able to, as far as we were concerned, reproduce our leak and also our sample value, here at probe one is a reasonable error.

For those that like to think about protection factors, whatever we want - fit factors, it boils down to a protection factor, in the first one, of 102 at the breathing machine. This is at the breathing machine where, as I showed you, we took our sample in the copper tube, versus the number one point on the lens. We have a protection factor measured of 102 versus 96 in the mask.

If we come down and look at the same thing on a duplicate, we measure a protection factor of 98 versus 100 in the mask. Now, we thought we had to start fiddling around and moving some leaks. As I

told you, leaks are a real problem. So the way these leaks were introduced is that we hooked on sample probe number four a needle valve so that we could leak into the mask at a known rate aerosol from the test chamber. So rather than fiddling around with the syringe, like I showed you before, that didn't give us any reproducible work, we created a different type of leak so that then we started introducing our leak on the far side of the mask using a needle valve.

The reason we picked the needle valve is we figured, well, we need to vary the area going in. But we found out that our fancy needle valve was really too accurate and we just tore it all apart and used the critical orifice as our inlet. I have it here and I will show it to those who are interested. But again, a little different -- you know, this whole thing of what it really means is that you have come back and make sure you know what was done in the study. So we have that type of a leak.

Now, if we come down and we say, okay, we take the inlet and we put a little hose on it and then we move it around to the exhalation valve area inside the mask -- so what I am doing then is saying this leak here comes in, streamlines, if you want to call it that, or whatever, but we take down through a hose and dump it into the respirator at the chin area, around the exhalation valve.

What we see is, yes, there is a difference. But if we take the breathing machine number versus sample probe number one there is no difference. Now, that is a fluke for sure -- 13 versus 13 - but not a significant difference. If we go across the rest of the respirator points, and please go across those, and you see there is not a big difference, not what I would call a significant difference

when we sample all over, one, two, three and five, on this respirator facepiece.

Now, if we come down to number four and we take it and we put it above probe three, a forehead leak, and you say, ah-ha, that is two extremes. And what do we find here? Again, not a significant difference in what the breathing machine sees versus what sample probe number one sees. Now, we do see some differences in two, three and four, bigger than the other ones. So again, there is some variability but if we remember that we always sample in this area, that is where you do your work, your quantitative fitting, we are not finding big difference between breathing machine numbers and sample point number one number.

I don't want it to be said that Livermore doesn't try the worst case. This was put on a separate slide because I was pondering whether I want to talk worst case situations. But I think it is instructive for us to look at this even in our analysis here.

If you see -- what we have done here, we have taken our leak at probe number four. My artist fouled up and I didn't have time to straighten it up but this is one, two, three and four is over on the far side and five is here. So we take the same leak at four, only we take the tube and we stick it in the mouth. And this is a streamline of streamlines. Okay, laminar flow, the best that you can get -- we run it into the mask. And we say, okay, what is happening in our system?

Now, the breathing machine comes up with a leak or a value on the photometer of 0.71 and we find about a 35 percent number here of 0.47. Now, you always want to analyze these worst cases because that

is where we really get excited. And what we came up with is if we do just a qualitative dilution number because, remember, the mask volume which comes out, in this case, to be about 1000 ml in the Survivair mask, 990-some ml - and somebody says how do you measure it? And you get your technician to fill it full of water and they pour it out and you measure it or you weigh it, whatever you like. And that was the way we were successful in getting some estimate of dead space in that mask.

What I want to say is we can even explain this qualitatively with the dilution but the big bottom line - not big variations; not big variations. And remember how absurd this condition is, this is a streamline stuck into the mouthpiece.

One of the things that worries me on this one is that we have probably a little higher delta P in that area so we may be pulling even more aerosol in from the chamber through that tube because we have changed the delta P that, that little tube is seeing, is drawing the aerosol in from the fit chamber. So I don't want anybody to walk away and say this is, you know, the sound part of the experiment. But it is the worst case and, again, we don't see what I would call significant differences under this very worst case situation.

Now let's look at the probe depth. What I have here is a series of slides showing you how we were able to use our probe. Note, this one is about three inches in.

This one dropped back to about half an inch in.

A quarter inch.

And an eighth inch or almost non-visible.

What did we see when we took readings with a leak in this area? The breathing machine number on the photometer worked out to be 0.6.

And here we are looking at probe number one where we do all our sampling, again, 0.6 versus 0.52; 0.6 versus 0.59; 0.6 versus 0.57; 0.6 versus 0.58.

Now, if you noticed on the experimental conditions before, my sampling rate was one liter a minute. Now, the only reason that changed on you, this was the first experiment we did. We have two other instruments that we did. We have two other instruments that we sample with in our apparatus and we didn't catch up time, up the flowrate on the photometer when we did this. But this is one-third the sample rate of the other one.

But again what are we seeing here in the full face respirator? We are not seeing significant variations in sample depth in that critical area where we sample, the nose-mouth area.

What can we conclude from this for number two? Significant differences are not observed at the sample locations normally used to evaluate respirator fit under what I call realistic laboratory machine test conditions.

So in recap, we entered this quick study to answer a key question, is there significant variation in the aerosol concentrations in the nose-mouth sampling areas during normal breathing when wearing a respirator which has a leak?

Warren presented his data that kind of stimulated our activity here because we were really concerned whether there was a possibility that we had overlooked something. These two questions, or statements, kind of evolved that we wanted to look into. Airflow within a full face mask is laminar. Significant differences are observed at different probe locations within a facepiece. Remember, Warren did his on a half; we did ours on a full.

What did we find? Turbulent flow;

reasonably good mixing in the nose-mouth area.

And that there are not significant differences in probe depth in that critical nose-mouth breathing area.

So what can I conclude? It is kind of like a tempest in a teapot as far as the old quantitative question right now, when we look at the full face situation, which is where we have been most serious about our quantitative fitting at the Lawrence Livermore Lab.

Now, I would like to talk a little bit more about an area about just quantitative fit testing because we did a little talking about this and I think it is worth a review and a few comments here. We saw historically that there were several reasons or several purposes for quantitative fit testing. We wanted to accurately and reproducibly evaluate a respirator on a manikin head using a breathing machine. So that is one type of quantitative fit testing.

Then we also wanted to look at respirator fits on various panels of respirator users to measure a fit factor maybe, if we keep up with the latest buzz or jargon in the area. And you want to remember that he identified the need for really different sizes of respirators. And we found that the market responded and now we have multiple sized facepieces to try and give the best fit we can.

We wanted to determine how a particular respirator fits a specific individual. Now, we use that a lot in our laboratory program. But, you see, the thing that we always want to remember too is that we have law right now that assigns specific protection factors for approved equipment. That is why at a protection factor of ten for a half mask -- why quantitatively fit. I mean,

it just doesn't make sense. If you are running a practical side of a program, it is not worth the investment. And on a full face you are a lot more serious and it becomes significant to make sure that you provide a fit all the time.

Now, the latest application and the one where I see we are getting into is, we want to talk about workplace protection factors. And a definition that I picked up for this is a measure of the protection provided by a respirator in the workplace under whatever normal workplace conditions are.

All these methods, and especially workplace protection factors, need to be conducted carefully and I think we need to show reproducibility. You just don't go out and grab one study and come back and say, ah-ha, something is wrong. Is it the mercury and swordfish that we need to think about that plagued the environmental business for a while? We saw analytical methods, and experimental protocol that produced the data, rather than true differences and what we were really trying to measure.

So when we think about workplace protection factors we have to be careful about analytical field measurement methods. Today is a good example. Look at the different kinds of experimental protocols you all have to digest. And what differences do they introduce into the final data? Workplace environment is not a laboratory environment. Contamination can be a problem within the laboratory and also in the environment. There are all kinds of multiple variables to deal with. There is cost. And really to what do we compare the results?

I find it hard to immediately take a workplace protection factor study and say, ah-ha, there is something wrong

with protection factors. Ed Hyatt, you dirty rat.

You know, that is what immediately comes to mind when I hear people jumping on us - where are we? You know, what do we do with that data? And I don't think we really know what the meaning of these results are because it is not straightforward.

And I couldn't resist taking a little here, and if we think about our situation, and I might think this little guy is a workplace protection factor, and I also might add that, you know, when you changed aerosols, guys - I have two aerosol physicists that work for me, they don't agree. If you want to get into the swamp, try and figure out how to get an aerosol physicist to reproducibly talk about things with you.

So if we change aerosols, and today what did we have? We had a vapor; we had acetone; we brought in a Ben Lieu 2.5 micron generated particle; I brought in a polydispersed polyethylene glycol; we had some salt; we had sulfur hexachloride; and these are all test agents with different detection equipment, all kinds of different things. So be careful when we think about changing the aerosol. And we have to be careful that we are not comparing apples and oranges. Thank you very much.

I wonder if there are any questions?

Mr. Wilmes: I have a question -

Mr. Johnson: Oh, I figured you might.

Mr. Wilmes: I guess on your videotape, on your jet stream, and I watched Warren Myers' demonstration earlier and I definitely saw a jet streaming -

Mr. Johnson: Well, we could see one, the first one at ten liters a minute, a very small one.

Mr. Wilmes: What I saw was the

inlet, your hypodermic needle was directly over the air inlet of the respirator, whereas, Warren's was at the face-seal leakage. Wouldn't you suggest that if you were the entire airflow is coming, that it would be less pronounced that what we saw with Warren's?

Mr. Johnson: As I said, leaks are a real problem. Now, the biggest thing you want to remember - this is my industrial hygiene training - is that to get a laminar flow system you have to work like the devil. If you put a push-pull system - and so the question is would you be favoring the turbulent over the laminar flow by placing it there? Our interest was to try and get a picture of what was going on in that mask.

Now, there may be areas in that respirator where you could get some kind of leak that would go in on a laminar basis. But what we did show is that as you up the flow, it becomes more turbulent. There is more mixing in there and so that placement, although it looks real close to the inlet, was probably about - if you look at the size of the respirator -- it only stuck in about an inch. So it wasn't as bad as the picture looked.

Mr. Wilmes: It looked about two to three inches in. It was right directly over the inlet of the respirator, about two or three inches from the seal. That is the way it looked to me.

Mr. Johnson: Well, we can run it over again but, you see, the key thing that you want to remember is that if there is a streamline and I introduced it back where Warren did, then where is all that mixing and turbulent flow that we illustrated in the respirator facepiece by putting it where we did? The same currents are still in there, no matter where the needle

is. The smoke is just introduced differently.

Mr. Wilmes: Any other questions?

Mr. Brennan: This is Bob Brennan, with Scott. I will make a comment and then a question. You have hexnuts from a quarter inch bulkhead fitting on the inside of the facepiece.

Mr. Johnson: Look it over. There it is.

Mr. Brennan: Right. I have not had occasion to look at this particular brand of full facepiece for sweep flow of the inside of a face shield but I do know that in several designs, as I stated earlier, there is a definite attempt to bring the incoming air swept over a smooth surface of the face shield and it sets up the basic current inside the facepiece. One of the things that you can do, and if you haven't done it - missed the first few minutes of your presentation so excuse me if you have done this - is introduce some visible smoke through the respirator while it is breathing on a breathing machine normally and look at the pattern in the facepiece, and do the same thing after you put your sample test probes in and see if you have disturbed the basic flow in the facepiece. Now, if there is a sweeping flow over this lens to keep it clean, it would seem to me that if you put a bunch of turbulence in that field, you may have generated a bunch of turbulence that wouldn't normally be in that facepiece as used. Now, you may have already covered this at the beginning of your presentation. You have to pardon me, I was out of the room.

Mr. Johnson: The original video was done with no sampling ports on it. So, yes, that is a very good point and, of course, that is the thing that we always have to be concerned with when we start tampering with the

device. You know, it doesn't then become the way it is being used because respirators aren't being used with sampling ports out in the field. So you introduce individual peculiarities when you do that. That is a very good point. Dave has been thinking very intently there, I have to get ready.

Mr. Swift: Dave Swift, Johns Hopkins. Go back over your worst case again for me. You ran a tube into the mouthpiece and at the same time that you ran that in, you sampled the probe from the face?

Mr. Johnson: Yes.

Mr. Swift: I wasn't quite sure. And you sampled some, and that was done in the inhalation and exhalation mode?

Mr. Johnson: All our data was done - you know, the chart that you saw, we did a full breathing cycle. We didn't fool around a bit with inhalation only or exhalation only or constant. We did it as the man breathes. So it was inlet-out. So the sampling was done in the pulsating mode with the material coming in and out of the same chamber, like your lungs work.

Mr. Swift: Okay. And there wasn't filtering?

Mr. Johnson: No filtering, no.

Mr. Swift: All right. But during that cycle then that so-called streamline produced by running the tube all the way into the mouth went in and then, presumably, what you sampled was the combination of what is mixed in that area --

Mr. Johnson: Right.

Mr. Swift: - and what came back?

Mr. Johnson: Yes. And the thing I wanted to say is that if I do a simple volume analysis, we looked at all of our tubing and the internal facepiece volume, that it works out to be about - to give us the right number but we are not going to jump and say it was a simple dilution. We think there is more involved when you put it into the mouth, you know, as a streamline and

then it comes back out, indicating the importance of dead space in a respirator.

So to summarize that test, the aerosol came in through the leak, went into the mouth through a tube so there was no ability for it to mix at all in the facepiece because it went in through the tube. All the aerosol that leaked into the respirator facepiece came in, was sucked down into the breathing machine cylinder and then discharged back out of the facepiece.

Now, again, this also points out the reason why a full cycle breathing machine is important, that you do inhalation and exhalation.

Mr. Raven: Raven, at TCOM, again. I really like this. One of the things that is important here is that when a person breathes in and out it is turbulent flow right at the mouth. It doesn't matter what he is breathing at, what rate he is breathing at, it is turbulent flow. He has a big tube there.

So I think he is just demonstrating right there that, that is your mixing point and you should sample right there.

Mr. Johnson: As has been done, as far as I know, in the field from the beginning. We had a little variation in size and volume but we always put the probe right in where the guy blew out, as best as we could.

Mr. Moon: Mike Moon, HSC Corporation. I notice that in your videotape the smoke was coming in even when the breathing machine was valved off. Was that being pumped in?

Mr. Johnson: No. What we tried to do there, we had a little bulb, squeeze bulb, so we were trying to get it in but we did not puff it in, as best we can, but it is a real problem because that stuff corrodes; your

needle plugs up; so we had all kinds of little varying applications but it was not a pressurized jet that you would blow in.

Now, one of the other things that you want to remember when we look at theories is that, again, you want to try and understand the data but smaller the point source, in other words, the smaller your inlet, the tighter it is going to stay as it goes through a streamline. So if you put a bigger hole or you put a bigger leak in there, the faster it is going to spread out. So we tried in this case to keep our syringe needle as small as possible to best simulate, you know, that streamline effect.

Mr. Matthiessen: Craig Matthiessen, with EPA. Our biggest concern is the workplace protection factor and taking into account your comments at the end plus some research that has been out, showing that the quantitative fit factor and workplace protection factor **don't** seem to correlate at all. Do you have any recommendations for how we can best judge what actually - how effective a respirator is in the workplace for workers?

Mr. Johnson: I think one of the things that I will say that is my personal biggest thing when I get into a respirator program or have been involved in running one is training. I mean, we, as **scientists**, we run around and we measure all these numbers and we will fight like the dickens about all these conditions, and it doesn't mean beans to that guy who is wearing that respirator. The key thing that it means to him, if you want a real program to provide good protection, is to train him and try and get him to wear it the way we test it, and he understands its limitations and how it works. And that is what concerns me when I go out and observe respirator users in big

first-class programs, with spectacle and, you know, the stems under the mask; I see then with the lenses out - I mean, it is easy, you just get rid of that lens and that is the way I have seen it. We have all seen the cigarette hole in the respirator. I mean, to us ivory tower respirator folks that might seem to be, you know, not good but that is where the real program saves and helps the people, back at the training. And in the future, as we work on this subject and better understand it, five years from now we are going to have a better handle on it.

Somebody has run a respirator program. That is about all I can say on that. I don't think workplace protection factors are going to answer the question for a while because it is an analytical and experimental nightmare to get something run that means something, that you can reproduce. How many people have gone back and reproduced a workplace protection factor study? Not many. And do you know why? It is cost. And the other thing is, well, they say the guys don't put the respirators on. So, you see, we are in a real catch-22 there.

Mr. Lanauskas: Stan Linauskas, from Chalk River in Canada. I reproduced a workplace protection factor study and underground uranium mine. The first study was performed, I would say, in 1978. And we did it in 1983 or in '84. And we essentially got the same results using different analytical techniques.

Mr. Johnson: I think that is the kind of data we really need to look at and get pinned down. I don't disagree with that. But that is what we need to see more of and intercomparisons thereof.

Mr. Sustello: Rick Sustello, from Wilson Safety Products. I understand you have only had a short

period of time in order to do this work and respond to Warren Myers. As you said at the end, you don't want to compare apples with oranges and I was just wondering, Mr. Myers' study used -- I don't know, 81 different replications of that data. How many replications of your data for your quantitative work have you done? Your qualitative work is nice but it is not very quantitative, you can't measure it; it is something visual and it is very hard to compare something visual with something that is measured.

Mr. Johnson: We have run two sets, two sets of data. And again, that is continuous - you see, the other thing that we want to remember, again looking at sampling systems, is that the photometer does provide you with pretty much a real time monitor, other than the lag of your sampling lines. So you get output immediately on that. So that your ability to run that for any length of time or go back and move through the system gives you a lot of good data versus, you know, a little different system where you dilute down or you have some problems with analytical techniques. I listed it as preliminary because we were scurrying just to get this but we feel it is representative, or I wouldn't be here.

I have the equipment up front for anybody who would like to take a look at some of our modifications and things.

Mr. Wilmes: Are there any further questions of any of the presenters today? I think they are all in the room, if someone has thought of something in the interim time.

Mr. Askin: Dan Askin, Askatech. Warren, could I - when you ran the streamlining effect, that was

strictly on a continuous inhalation, was it not? Or did you get pictures of that on an exhale basis only?

Mr. Myers: The demonstration I had over here was inhalation only. We have done it on inhalation and exhalation cycling. The streamlines are definitely present during inhalation. The exhalation routing back to the respirator does not destroy the streamlines that occurred during inhalation. And I just used that constant flow over here. It was an easier demonstration than bringing a breathing machine.

Mr. Askin: I would like to make one comment from some field work we wound up having to do. We were trying to locate the source of contamination in a clean room and the end result of solving the problem was going to full face respirators. Individuals were inspecting parts and introducing the contamination under a laminar flow hood at 100 feet per minute because of nasal trajectory velocities and particulates carried in oral trajectory velocities, depositing particulates on the parts while they were being inspected. We measured at 85 liters per minute roughly 3000 feet per minute in a pursed lip oral trajectory velocity. And in the tight confines of a respirator mask, I have difficulty visualizing that, that air is not continuously turning over because you have air coming down in this direction, rebounding to get down to the inhale valves and also back out to leaks.

Mr. Wilmes: Any other comments from anyone? All right, if not, we will adjourn until nine o'clock tomorrow morning.

More excerpts from this Critical Issues Conference will appear in the next issue of the ISRP Journal.