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Data Acquisition and Control

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PROCEEDINGS OF THE WORKSHOP ON GEOMEMBRANE SEAMING:

DATA ACQUISITION AND CONTROL

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Work Assignment Manager
Robert E. Landreth
Municipal Solid Waste & Residuals Management Branch

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Risk Reduction Engineering Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report summarizes a workshop to examine the feasibility and advisability of developing seam welders for geomembranes that would, in the process of welding, gather data on seaming parameters. The intent of the data gathering would be to provide continuous control of the welding process so that defective seams would be eliminated or become much less prevalent. Defective seams in geomembranes are the principal sources of leakage to the environment from waste containment systems such as landfills and surface impoundments.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

The U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory, in cooperation with the Geosynthetic Research Institute, sponsored a workshop on Geomembrane Wedge Welding Seaming. Data Acquisition and Control on April 22, 1993. The workshop was held at the Andrew W. Breidenbach Environmental Research Center in Cincinnati, Ohio. The 109 workshop registrants represented geosynthetics manufacturers and installers, waste management facility owners and operators, construction quality assurance personnel, and Federal and State environmental regulators.

The workshop discussion centered on geomembrane seam welders, in particular wedge welders and recently developing data collection devices that may be attached to a welder to help improve the seam-welding process. The data collection devices may be designed to automatically control the welders by responding to the variables that affect the welding process. The variables include sheet temperature, wedge temperature, nip roller, pressure, speed of welder movement along the seam, power input, air temperature, and other parameters as desired.

Several variations of data acquisition welders, or "smart welders," were described, along with their capabilities, which usually include data logging and the ability to directly enter the collected data into a computer for data manipulation and potentially for feedback control.

A large number, but perhaps not a majority of the participants, favored development and use of the data acquisition welders. They believed that such welders would improve the quality of geomembrane seams by taking away some of the human error factor, and by making it possible to constantly check seam quality in real time as the welder advances along the seam. Currently, the seams are checked by destructive tests, in which sections of the seam are cut out at selected intervals and subjected to o\peel and shear tensile tests. Construction quality assurance firms generally favored the opportunity that the data acquisition welders offered in assisting them ensure seam reliability.

Not all participants favored data acquisition welders at this time. Some believed that the expense of retrofitting the industry would be excessive compared with the improvement that would be achieved in the welding process. In general, these participants believed that current welders were adequate and that operator training and craftsmanship were better points to emphasize. Some advocated the cautious approach, preferring to first study the need and define the causes of inadequate seaming. Most of those who were, however, somewhat negative were still involved in the development of data acquisition welders and clearly interested in their potential capabilities.

This report has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

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WORKSHOP ON GEOMEMBRANE SEAMING: DATA ACQUISITION AND CONTROL

INTRODUCTION

ROBERT E. LANDRETH, EPA

The purpose of this workshop is to discuss and disseminate information about welding geomembrane seams. More specifically, it is to discuss "Data Acquisition Wedge Welders," or wedge welders that have been fitted with devices for sensing, displaying, and using information on the conditions that control seam quality during the welding operation. Some of these devices can actually control the seaming process in real time or near real time.

In the workshop, we hope to hear from the developers of the data acquisition welders and have them describe to us their features and perhaps the advantages, or at least the perceived advantages of one measured parameter over another. The developers of the machines will be here to directly explain their operation to the Federal and State regulators, geomembrane manufacturers and installers, facility owners and operators, and construction quality assurance personnel. Each of these communities is requested to respond to what they hear, and to provide their opinions regarding the potential utility of these devices in improving the seaming process.

A list of workshop participants is presented as an appendix to this report.

The workshop will begin with an historical overview of geomembrane seaming and welding and the need to improve the process. The overview will be followed by technical presentations by those who build and work directly with the device owners and operators of the facilities constructed with geomembranes, geomembrane manufacturers and installers, construction quality assurance personnel who must approve the installed geomembranes, and State regulatory personnel who must certify a geomembrane installation as ready for use.

CONCLUSIONS

This Workshop clearly demonstrated that data acquisition hot wedge welders are not some type of futuristic concept or dream; they are a reality. Both the National Seal Company and Gundle Lining Systems, Inc. have fully functional systems which are working in the field accumulating data. At the minimum, they types of data include:

- Power input
- Nip roller pressure
- Wedge temperature
- Rate of movement (speed)

Beyond the above, the different systems can read a host of other parameters including:

- Upper sheet temperature
- Lower sheet temperature
- Air temperature
- Relative humidity

Furthermore, the various parameters can be read in real time or stored for subsequent data retrieval and printout.

Steps are ongoing by both companies to correlate the above parameters to good or bad seam strengths (primarily peel strength). In this regard, the Workshop clearly set forth the concept of a seaming "window" or seaming "bubble". These terms relate to the two-dimensional space of wedge temperature vs. rate of movement, or the three-dimensional space of wedge temperature vs. rate of movement vs. nip roller pressure. The quest of good seams, of course, is to stay within the window or bubble as ambient conditions and surface features vary.

It was also brought out that data acquisition welders were not strictly for polyethylene (HDPE, VLDPE, and LLDPE) geomembrane seaming and that <u>all</u> thermoplastic geomembranes can utilize such seaming devices. This includes PVC (per the presentation by EPI) and all other commercially used geomembranes, e.g., CSPE, EIA, PP, FCEA, etc.

As enthusiastic as the speakers for the above-mentioned companies were, others were quite skeptical. Concerns were raised as to the following issues:

1. What were the fundamental goals of such data acquisition wedge welders?
2. Do we have the essential knowledge to determine between good and bad seams?
3. What benefits will derive from such smart welders?
4. Will the data obtained be used in a negative manner against installers who use such devices?

5. What will justify the added cost of data acquisition wedge welders insofar as monetary payback to the installers?

Even further, some speakers stated that emphasis for making good seams should be placed on training courses for the welding personnel, not greater sophistication in the equipment.

Obviously, there were many (if not most) of the 109 participants who were somewhere between the above-described two extremes. As described in the text of this report many of the participants voiced their opinions accordingly. While it is always dangerous to make broad statements according to groups, a generalized sensing seemed to indicate that:

- The installers were mixed in their opinions from enthusiastic to negative
- The equipment manufacturers were obviously very interested
- The owner/operators were clearly interested and were generally receptive if a fundamental cost effectiveness could be eventually shown
- The consultants were quite positive and clearly willing to investigate the devices more closely
- The regulators were cautious in their remarks and quite noncommittal.

From the opinions voiced it is clear that some installers will use the devices immediately and that the industry should expect to see data acquisition, i.e., "smart", welders in the field. These installers will be in a data acquisition phase with comparisons being made to destructive tests made in the conventional manner. Value decisions will be made, on a company-by-company basis, in the immediate future. As the results unfold, others will be enticed to use data acquisition welders, or be discouraged. Obviously, time will tell which outcome will eventually be realized.

RECOMMENDATIONS

Insofar as recommendations for this Workshop on data acquisition, or "smart", welders are concerned, it is felt that the devices should be welcomed on job sites. Those installers involved should be encouraged to develop the concept to its fullest potential. The data analysis and correlation to destructive test data lie at the heart of the value of the equipment.

If positive correlations are shown, one should certainly consider decreasing the number of destructive tests and the use of control charts, or the method of attributes should be utilized to augment the smart welding devices. Obviously, the hard copy data obtained should be part of the final CQA document.

In this respect an interesting aside came about during the Workshop. That is the identification of good-vs-bad seam via destructive peel tests. Clearly, some additional research is recommended in this regard. Furthermore, such research should consider both the short-term and long-term aspects of seam strength.

Beyond data acquisition, however, lie computer-controlled wedge welders. With an onboard computer, loaded with the proper algorithm, actual control of the welder potentially can be achieved. This control would most likely be on the rate of movement (speed) of the device. For example, if a cloud temporarily covered the site, decreasing the geomembrane's temperature, the computer would sense the drop in temperature and instantly correct the situation by decreasing the speed of the device. More energy would thus enter the seam area and the proper position within the seaming "bubble" would be maintained.

Thus, with all of the questions raised at the Workshop (goals, cost, direction, accuracy, etc.), it is felt that the general recommendation should certainly be to utilize the devices wherever possible, by whoever is willing to become involved. There is no inherently negative aspect of data acquisition welders and the potential is quite strong. The next few years should be carefully observed by all parties involved in geomembrane seaming and the experiences conveyed to others by those willing to become involved.

It is hoped that the Workshop will spur all aspects of the geomembrane industry (regulators, owners, consultants, test laboratories, installers, manufacturers, etc.) to put down their thoughts regarding data acquisitions welders in technical papers. By presenting these papers at other conferences, symposia, meetings, etc., a continuing dialogue will be generated and eventually the technology of geomembrane seaming will be improved. The question that ultimately remains is how much it will be improved.

OVERVIEW

ROBERT M. KOERNER, GEOSYNTHETIC RESEARCH INSTITUTE

A successful geomembrane installation has numerous elements and certainly field seaming is as critical, if not more so, than the others. Therefore, it is only proper that we focus on field seaming and on the latest developments. I have had a large, ranging contract with EPA over the years to look at various innovations. About two years ago automatic welders, or data acquisition welders, came on the scene via a number of manufacturer-installers. We (EPA and GRI) have followed welder development and thought it was time to put together this workshop. Perhaps a few introductory remarks are in order to bring us all to the same point before the people who are actually doing the work make their presentations.

The original development of hot-wedge welding appears to have been in Europe. It was brought to the United States about 10 years ago. The method is available in two styles: the single wedge or the double wedge with an air channel, of which the latter certainly is the most widely used. Hot-wedge welding is used at this point by all polyethylene manufacturers. All polyethylene installers and manufacturers are using wedge welding as their primary welding source. Of course, they still use extrusion fillet welding for details, but certainly the wedge is at the heart of their field installation.

Please recognize that we are using all thermoplastic geomembranes in this business. Thermoset geomembranes have essentially disappeared. The definition of a thermoplastic is that it can be melted and fused back together in roughly its original form, and so the hot wedge technique can be used on all thermoplastic materials.

Figure 1 is taken from the original patent in the United States in 1979 and is a cross-section of the device at that time. It has undergone modifications obviously in the 13 years since then. The two sheets to be joined together are brought into contact with the wedge. They are in intimate contact with the wedge, depending on the size of the wedge, for 1.0 to 3.0 in (25 to 76 mm), in turn depending upon the slope and the size of the wedge. The sheets are brought together by squeeze or nip rollers as they leave the device. As the device travels from your right to your left the two sheets are joined together in their final form. For those of you who are concerned over patents, the people who had this patent, to my knowledge, have never enforced it. Thus, wedge welding is not a litigious area, at least as far as the use of wedges is concerned at this time.

In the remarks to follow, I would like to talk about six items; (1) What are the operational variables that are involved? (2) What wedge controls are involved, at least that can be readily controlled? (3) How do these controls affect seam strength? (4) What is the concept of a seaming window? Or if you think in three-dimensional space, a seaming bubble? (5) What are the current destructive seam test strategies? (6) And finally, what will upgrade the current wedge-welding technology?

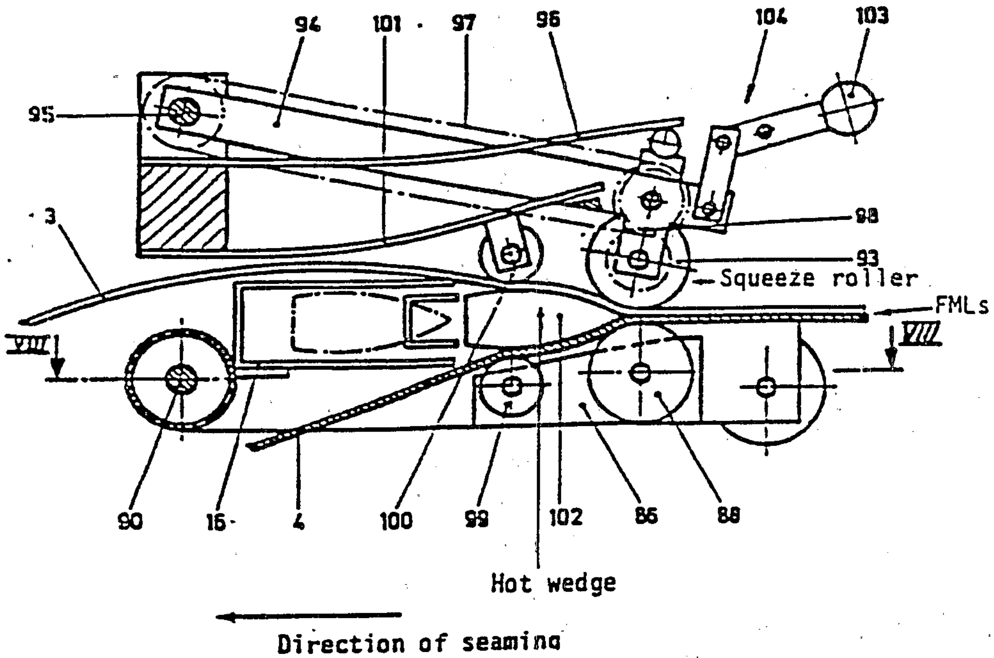

Figure 1. Schematic of hot-wedge welding device taken from U.S. patent 4,146,419 (March 27, 1979).

1. Operational Variables

There are a large number of operational variables. How much they influence the strength of the seam is largely open to debate. But nonetheless, the type of the geomembrane, its thickness, its texture, the temperature of the sheet, and the orientation of the sheet, probably all play a part in some respect.

Another category of items has to do with the ambient environment in which the sheet is being placed. What is underneath the geomembrane? Is it a geotextile? Or a geonet? Or is it soil? What is the moisture of this substrate? What is its temperature and how does its temperature influence the temperature of the sheet that you are trying to join? What's the surface contact?

We know that often these geomembranes are not placed tight. When you have a wave due to expansion of the material and you are going up over the wave, how does this influence things? What is the atmospheric temperature and its humidity? And of course how does the atmospheric temperature interact with the sheet temperature and its condition?

Clearly the seaming device itself a variable. What type of device are you working with? Where is the location of the thermocouple? Not that this is important, but it is if you are trying to compare the temperature of one wedge device to the temperature of another, which might not have any relevance at all. What's the type and shape of drive wheels? What is the input power to the device? Is it constant? Is it what is required for driving that particular wedge?

And then lastly, what are the human-related features of wedge welding, or any other welding? What is the atmosphere temperature that the people are working in? What's the location in the facility? Is it along a straight type of production seam or in a corner? What's the time of day? Is it getting near the end of the shift? Other things which the seamer might be thinking -- why am I here in this landfill and not at home with my family? The seamer has a task to do in order to bring all of this together.

2. Readily Controllable Wedge Parameters

The three things that the person has to work with are clearly the temperature of the wedge, which can be set on all these devices to my knowledge; the speed of the device, which certainly can be set; and to a lesser extent, but nonetheless a controllable variable, the pressure of the nip rollers.

3. Wedge-Welder Controls vs. Seam Strength

People have tried to put their arms around these three variables (temperature, speed, and pressure) as far as seam strength is concerned, by testing seams in either shear or in peel. There are probably five or six papers in the open literature. The installers certainly have a much greater data base than anybody doing research and development on a few little odds and ends, but nonetheless, there are general indications in the literature. André Rollin from Ecole Polytechnic in Montreal has probably written the most about the topic and given general kinds of variations. But I submit to you that such studies are greatly generalized, and very much idealized. The data are subjective and they probably are not transferable.

4. The Seaming Window, or Seaming Bubble

Generally, the seamer adjusts the three controls (temperature, speed, and pressure) to suit site-specific conditions based on test strips. Then the installer goes out, with the machine set accordingly to make production seams using the controls established on the test strip. The seamer then adjusts those controls during production based on experience and intuition. That's where the glitch comes in, because the seamer is trying to sense, I believe, the concept of a "seam window" (Figure 2). In two-dimensional space, meaning that, as the temperature varies, (ambient temperature versus sheet temperature), should the speed be adjusted? In other words, if a cloud goes over the site and the geomembrane gets cooler, should the device be slowed down? How much should it be slowed down? And vice versa if it gets warmer? In a similar way, there's a window for temperature and pressure, and, of course, these three variables, temperature, speed, and pressure are what the seamer has to work with. If we put the three of them together, we really have, depending on the seamer and how the seamer thinks. And, if he can think in three dimensions, a three-dimensional space or "bubble" (Figure 2). The quest for the seamer is to stay as close to the center of that bubble as possible.

The problem, of course, is that you never know where you are in the bubble. Are you at one boundary ready to pop out for inadequate or excessive speed at another boundary ready to pop out for temperature, or are you indeed right there in the center where you can stand a considerable tolerance and variation in all these variables that may affect the seam? This concept of a seaming bubble is very nice and we would like to stay as close to the center as possible in order to get high quality seams as indicated by good destructive tests in shear and peel.

5. Current Destructive Seam Test Strategies

QA personnel, of course, are constantly challenging the quality of the seams. This is their job. This is their right. This is what they should be doing. This is how they report to the owner/operator and to the regulator. The current state of the art is to cut destructive test samples out of the production seams. Over the years, EPA has investigated many specifications and the sampling interval typically is from one destructive test per 250 ft (76 meters) of length at the highest frequency to one in a 1000 ft (305 m) of length at the lowest frequency. Many specifications are written at one per 500 ft (153 m), as recommended by Henry Haxo in EPA's 1988 Technical Resource Document. Within the region where one test is taken per 500 ft (153 m), the QA firm will either have a uniform repetitive spacing or a random spacing. Certainly more and more QA firms are taking a random sample within whatever the interval is. The length of the destructive test sample varies according to the degree of QA work on the job, from 12 in to 40 in (30.5 to 102 cm) in length along the seam. Whatever this sample length is, it is then distributed to the owner/operator for archiving the QC firm and the QA firm for actual testing.

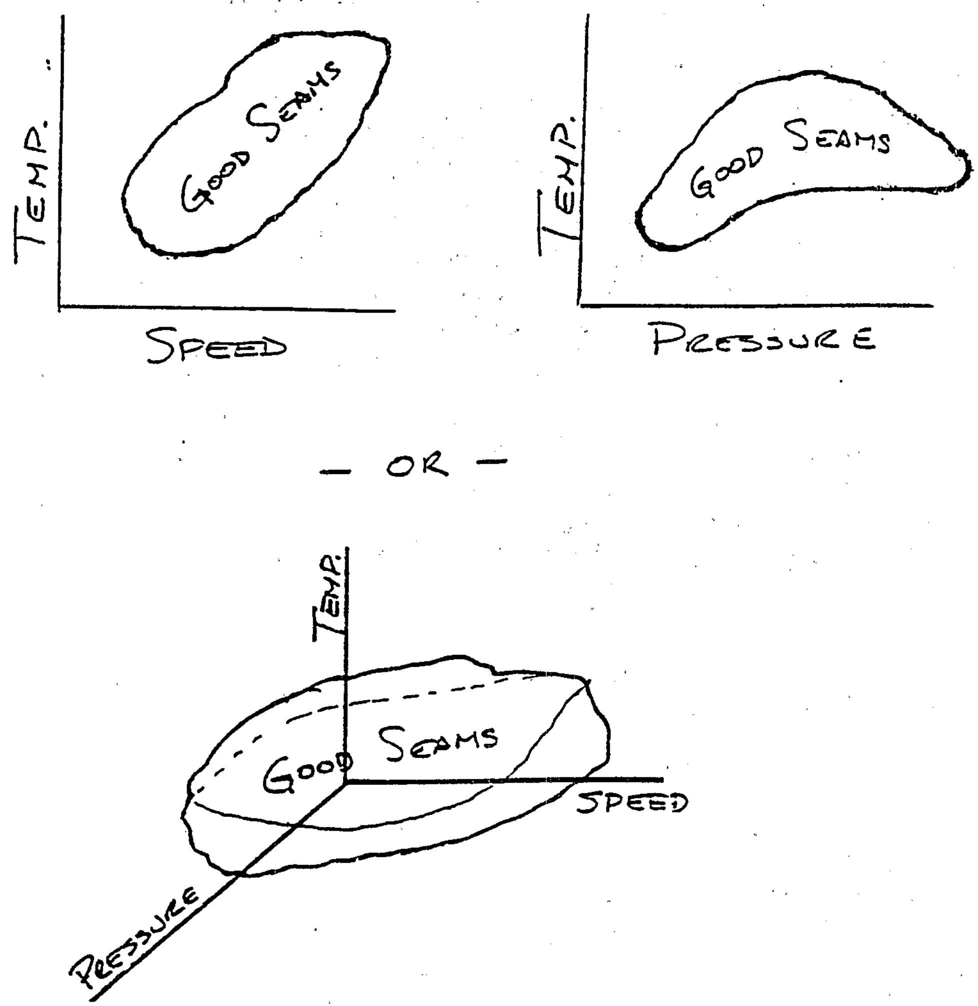

Figure 2. Concept of "Seam Window" and "Seam Bubble".

Finally, the test area where the sample has been taken is repaired by patching or by a cap strip. Why a cap strip? Well, if the sample fails in either shear or peel according to the specification in the QA plan, and that's a moving target at this time, then generally two additional destructive tests are taken bounding the one that failed. They are typically 10 ft (3 m) on each side of it. So now you have three holes in the geomembrane at this point. You test both samples, and if both are OK on either side of the failed sample, generally a cap strip is put over that area, depending on what the QA people feel is required for that particular situation. If one or both of those additional samples fail, you continue in 10-ft (3-m) increments, ad infinitum, until you finally bound the area, and then when success is finally achieved, a cap strip is placed over the entire area, or the entire length of the seam. A vacuum box or an air lance is applied, depending on the kind of geomembrane, for a non-destructive test to the entirety of this cap strip. Obviously, you have destroyed any possibility of doing an air-channel test at that point.

Generally the geomembrane installer is not penalized for failures. I'm sure there are modern QA plans written now where, if you do have failures, you have to begin taking more destructive tests, but, I think in general the state of the art is that the installation procedure is not adjusted whether he does a poor job or an excellent job. Of course the payback here is that if you do a good job, you have less failures and, from what I gather, each failed destructive test is worth about a thousand dollars; some people even say more than a thousand dollars. Failures give not only an unsightly job to be repaired, it also costs the installer considerable money.

On the other side of not being penalized, the installer is not rewarded for doing a good job, such as opening up the spacing and taking fewer destructive samples. We now have a document which Greg Richardson wrote for the Agency, EPA/540/R-92/073, that gives two methods that a QA firm can utilize for taking fewer samples if testing so indicates. One method is by control charts, and the other by the method of attributes. Both indicate, if you are doing a poor job, you have to take more tests and if you are doing a good job, you take fewer tests. So there is a way of getting out of this, but nonetheless, the current state of the art is that you lock in on the spacing indicated in the specification and you continue, irrespective of failure or successes, as far as your destructs are concerned.

6. <u>Upgrading the Technology of Wedge Welders</u>

Perhaps there are some needs and some desires, although I recognize it's a bit presumptuous for me to say this. I think there are some needs to upgrade wedge-welding technology and certainly one of them, at the heart of our workshop today, is to modify wedge welders for data acquisition.

Rest assured that in this workshop we are not breaking completely new ground. The German complement to the EPA is already requiring data acquisition on their production seams in the field. So we do have someone to follow. The retrieve data should probably include the basic three variables, namely nip roller pressure, temperature of the wedge, and speed. It obviously requires some type of display and/or recording. Furthermore, the data should be capable of being retrieved and subsequentially evaluated. Why are you taking the data if you are not going to look at how it compares with the destructive tests and how they are going? And finally we should archive the data to give credibility to the fabrication of the particular seam, or seams, in question.

There are also some desires. Clearly, one is to correlate the data from the welder with the corresponding destructive shear and peel tests. You are going to hear about that this morning. Tests, in fact, are being done.

Second, it's possible to have online monitoring of ambient conditions such as temperature and humidity at the site, and perhaps even the sheet temperature immediately ahead of the wedge. You are going to hear about that also today. Third, if you have online monitoring, and if you have correlations to successful seams from destructive tests, then certainly you could have a computer on board with an algorithm saying where you should be with respect to the seaming bubble. And finally, if you've gone that far, you might want an automatic feedback loop to modify one of the three basic parameters so that you are remaining in the center of the bubble that we are envisioning. There are numerous other details, but you're going to hear about them today from Gary Kolbasuk and Fred Struve, and perhaps other speakers as well.

As all of you probably know, I don't do this for living, so let's hear about it from the people who really do hot wedge seaming. In particular, let's hear about data acquisition wedge welders. Thank you very much.

SUMMARY OF TECHNICAL PRESENTATIONS

Gary Kolbasuk - National Seal

I'd like to start off by telling you what I think I'm talking about, so you have some idea of my thoughts. I am going to do that by starting out with a couple of definitions which are two aspects of the same subject. They are data acquisition welding and process control welding. I view data acquisition welding as monitoring parameters that can determine the quality of a product and comparing the values to limits known to produce a good product. Data acquisition is more passive where you are gathering data and having choices about how you might use it. Automation and data acquisition might have alarms to show when you get outside of a weld window, whereas process control welding is monitoring those parameters and maintaining the parameters within known limits -- limits known to produce a good product. With process control, you might have the computer continually looking at where you are within your welding window or welding bubble and constantly making adjustments to keep you there.

What is being proposed has at least a possibility of establishing welding windows for the materials and the welders that we have, setting up data acquisition to keep track of those, making sure that we're within the welding window, and then doing whatever additional controls that we can to help keep us there.

Two more quick definitions-- which are fairly obvious. The control variables are those that are readily controlled and selected for control, things like speed and wedge temperature. Uncontrolled variables are either not readily controlled -- things like air temperature -- or things that are not selected for control, like sheet temperature, for instance. You could argue that you could preheat the sheet coming in so that your welder always sees the same temperature sheet. But I'm not going to choose to do that, and I'll consider that an uncontrolled variable. A welding window is at the heart of what we want to do (Figure 3). Not only do we want to be within the welding window, but we want to be within some sort of a central portion. I wouldn't want to be welding a seam with the welder being out at points R or T. I'd like to be in the middle of such as points as much as possible.

The parts of the welding process that I am concerned about include five parameters: (1) temperature of the incoming sheet which is measured by infrared sensors; (2) the wedge temperature measured by a thermocouple; (3) the speed of the sheet as it goes through the welder which will be measured by the motor speed; (4) the force pressing the sheet against the wedge as measured by a load cell; and (5) the force joining the two sheets together, also being measured by a load cell.

We started out a couple of years ago trying to understand a little bit more about our welding process. We took a welder, stripped its mobility, placed it on a table, bench-mounted it, and then attached a lot of electronics to it. We attached electronics for monitoring anything that could move, anything that could apply pressure, have pressure applied to it or could change temperature, and fed all that data through a computer where we could take a look at what was going on. It was very enlightening. It gave us a lot of information, not only about the welding process, but about the design of our welder.

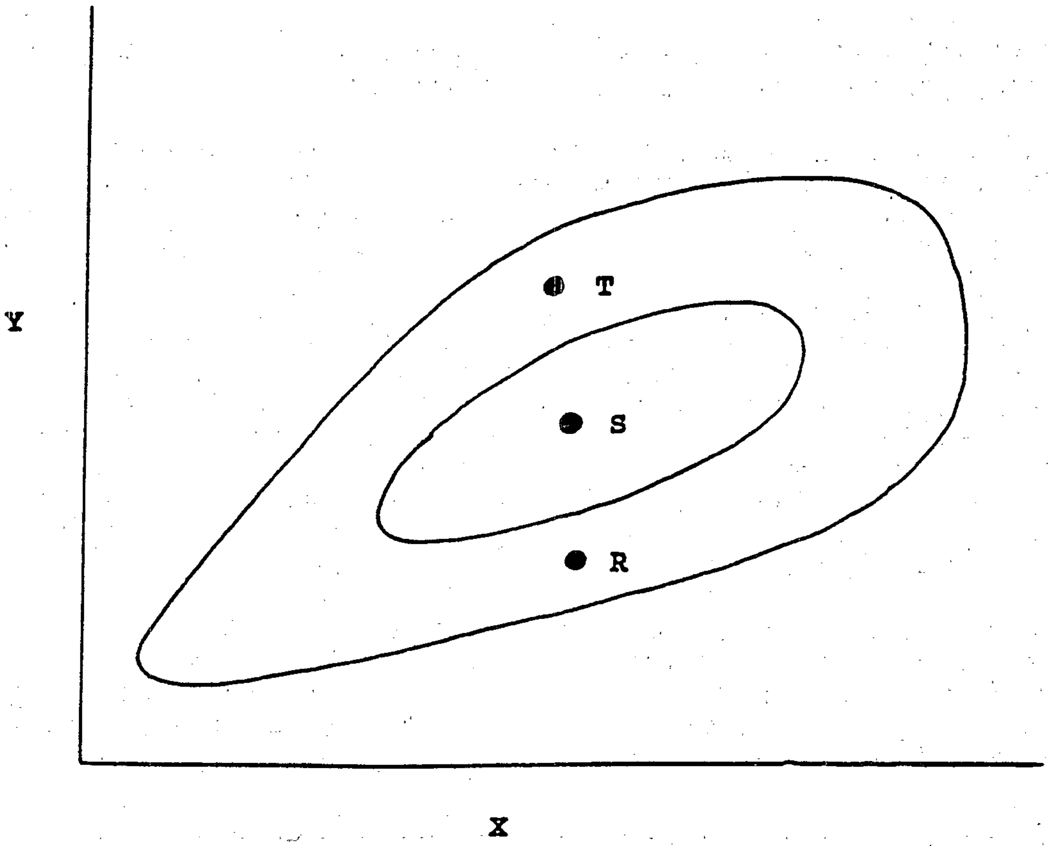

Figure 3. Welding window and preferred portion "S"; less-preferred portions "R" and "T".

From there we wanted to take it out to the field, so we had to take the electronics and pack it into another box so that we could make it mobile.

What I want to really emphasize from the beginning here, is that this is a research welder. This is not what I am proposing as a final data acquisition or process control welder that we'll make by the hundreds and supply everybody with. This is a machine that we are using in the field to learn about welding and what's going on in the field. We have sent it out there and gathered information on a number of jobs.

Inside a large box we have a computer or data logger, storage can for information, and a rugged floppy that can be taken out and downloaded into a computer. We have an onboard printer which can print out all the different parameters that we are monitoring. In this case, we have some 25 pieces of information being recorded every two seconds, which is considerable overkill. When we go to an actual field version, we won't need that much storage. We won't record that much data, that many parameters or even every two seconds. We'll be able to reduce the electronics considerably.

We have an encoder on the end of the DC motor for determining the motor speed and, therefore, the speed of the welder. We have infrared (IR) sensors. These IR cameras fit in a housing. One small camera faces down to measure the temperature of the top of the bottom sheet, and one faces up to measure the temperature of the bottom of the top sheet. We feel that the liner temperature is a very important variable in the welding process.

A load cell is attached to the drive wheel actuating mechanism. There was some concern about things like wedge position and making sure that they stay constant.

One of the things the process control welder does not do, or at least our research welder is not set up to do, is to deal with contamination or soil on the liner. We want to eliminate any sort of concern of contamination. We have a tape on the geomembrane in the welding area. We pull it off in front of the welder as we go along, so we don't have to worry about the variable of contamination.

Obviously temperature it is already a control variable. Thermocouple location is very important, and, as Dr. Koerner mentioned, wedge temperature by itself doesn't mean a lot, because when you say wedge temperature, you are implying that the entire wedge is at the same temperature. When you are welding, there are temperature gradients within the wedge, and there can be variations in temperature of 100°F (56°C) at any given location in the wedge. You have to be very careful when talking about wedge temperature, and thermocouple location, making sure the thermocouple is placed somewhere useful for monitoring the process. What we're hoping to accomplish with the type of welders we are talking about today is mostly data acquisition. With respect to wedge temperature, we want to make sure that we have devices that are controlling wedge temperature in a reasonable fashion.

When a weld begins, the temperature drops as the heat is taken out of the weld (Figure 4). It takes a while for the controller to realize what is going on, and it is programmed to make changes slowly so that the temperature comes back up slowly. In this case, it took about a minute for the wedge to get back up to temperature, which is not a major thing, but it is important to know that the wedge is being controlled near the set point, which in this case is 700°F (371°C).

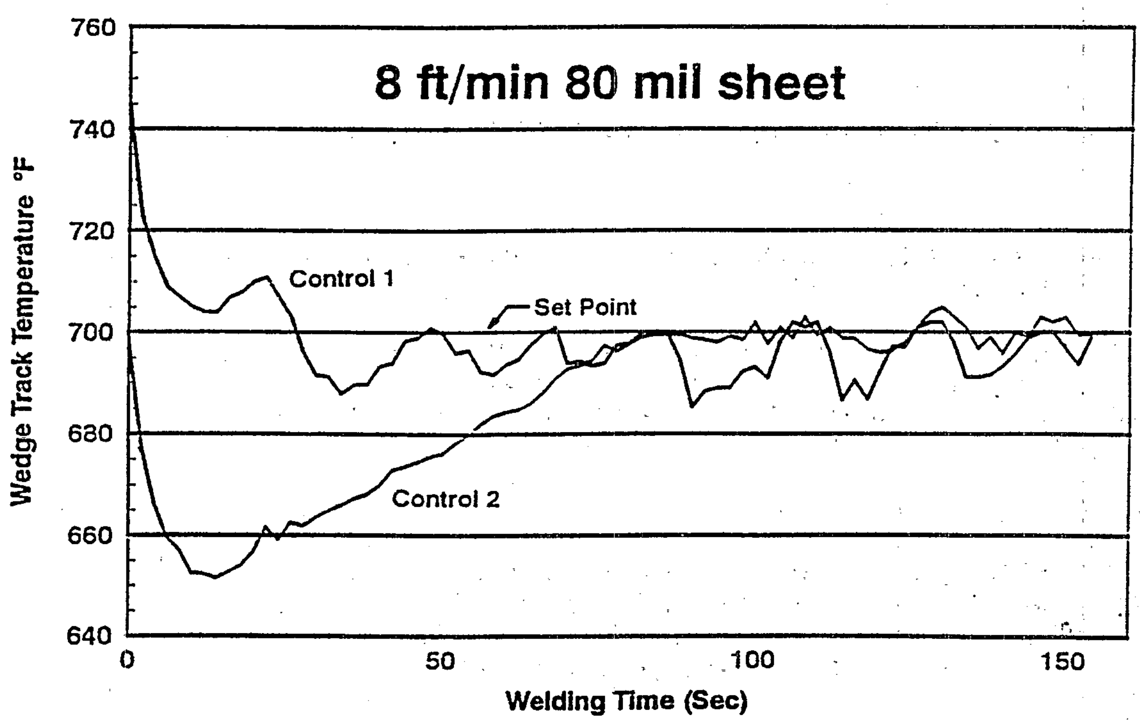

Figure 4. Wedge temperature vs. welding time during seam weld.

I feel that sheet temperature is really very important, because what we are trying to do is take the sheet temperature, at whatever temperature it is, raise it up to some *ideal temperature where we want to* join it together. If the sheet temperature varies during the welding process by say 50°F (28°C), then the amount of heat that you have to put into the sheet to bring it up to the ideal temperature also changes.

Figure 5 shows sheet temperature taken from a site in Michigan where we started out with the sun on the liner and a temperature of the sheet at about 145°F (63°C). A cloud came over; the temperature dropped down to about 95°F (35°C), so we had a 50°F (28°C) swing in a short period of time. All of the little peaks are not noise in the data. They are real temperature variations. The liner is lying flat on the ground conducting heat into the ground, so it is staying cooler. Wrinkles that are up in the air facing the sun are insulated and receiving a lot of solar heat, and so they are hotter. The last thing to note about this is the line at the bottom of the graph. It is ambient temperature. I won't say ambient temperature is a useless data point, but it certainly doesn't show what is happening with the sheet.

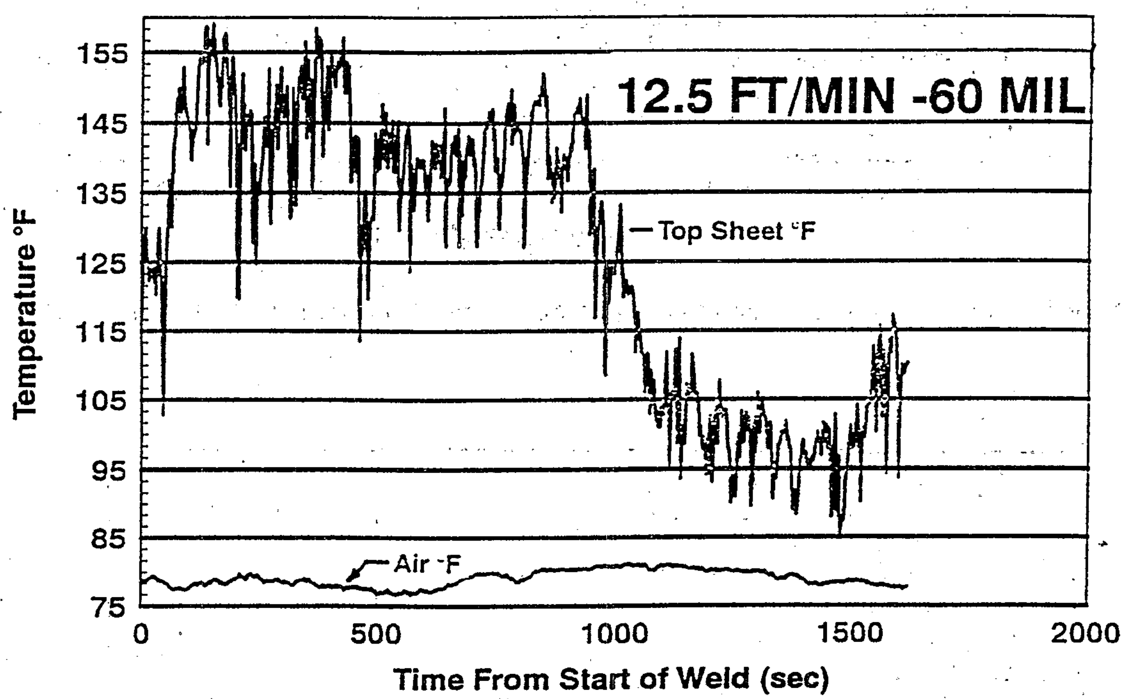

Figure 5. Top geomembrane temperature and air temperature vs. time during weld.

Figure 6 is data from another sheet. At the beginning of a day, the seamer starts out and it's cold. Temperature fluctuation on the liner is only a couple of degrees. The sun comes out; it starts warming up; you see ambient temperature coming up slowly, but the sheet temperature comes up much quicker. As the sheet temperature comes up and you start forming wrinkles, you get those larger spikes in the temperature profile again.

Figure 7 is a version of what a welding window might really look like, at least from some of our data. Realizing that the welding windows are unique to the liner thickness, the resin the liner is made with, the welding machine, and many other parameters that are set on the welder. Generating a library of welding windows a very laborious task. But in this particular case, you can see a huge welding window. It looks pretty good. You should have no problems. The clear area is where we are making good welds; up in the dark area on the left is where we are making welds that peel apart; the lower right area is where I consider them to be too hot. Too hot shows up either by failing peel strength or by badly distorted welds.

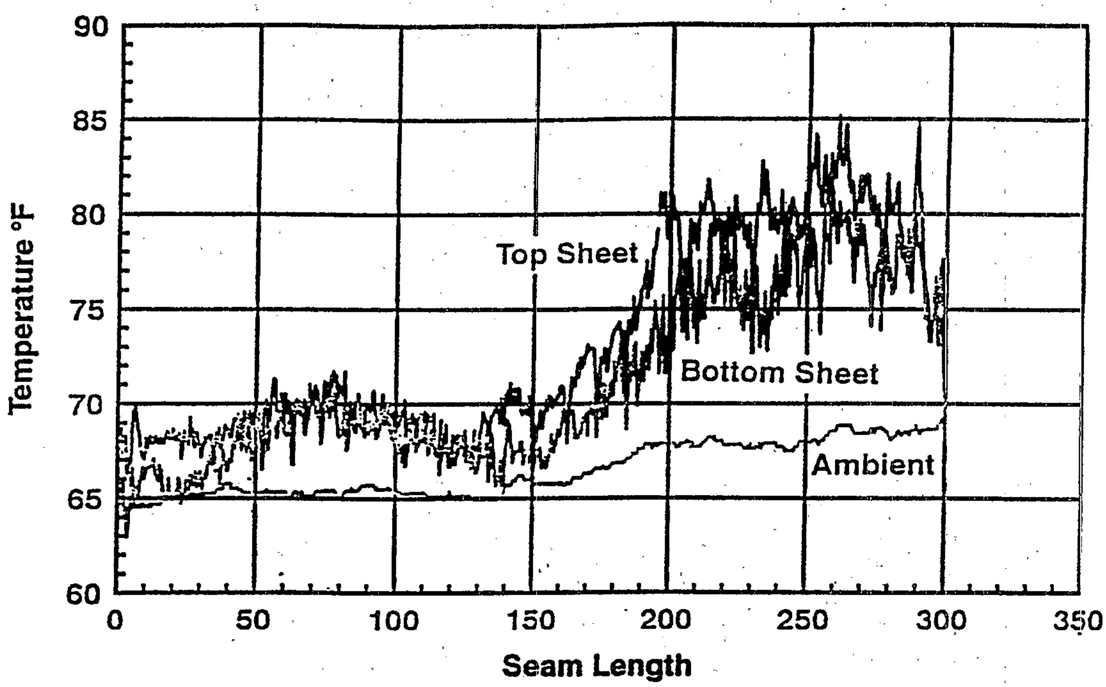

Figure 6. Top and bottom geomembrane temperature vs. air temperature during weld.

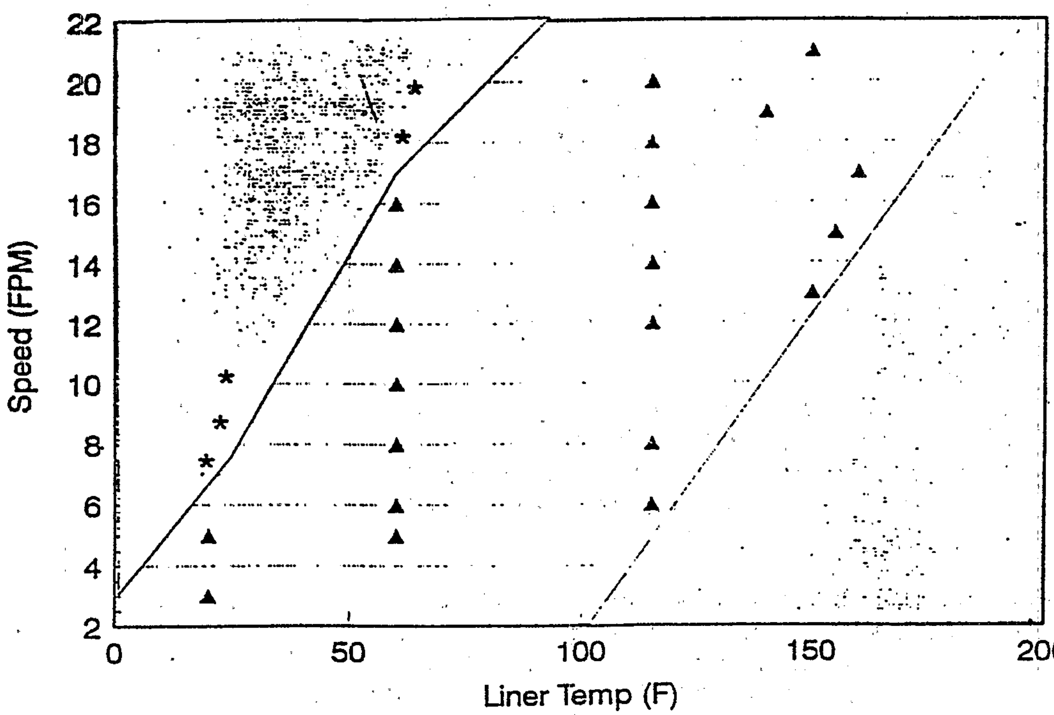

Figure 7. Welding window from real data for Resin A at 750°F (399°C)

On numerous occasions we have found in the field that as we go along in welding, we start out in the center of the weld window, a nice spot say like 12 ft/min (3.7 m/min) on a 100°F (38°C) liner. We're welding say 60-mil (1.5-mm), and we're getting over 100 lbs (45 kg) peel strength. We're going along just fine, and as the day goes on, the liner gets hotter. The values we get for peel continue to come down, until all of a sudden we're at 88 lbs (40 kg) and not meeting the 90-lb (41-kg) spec. What we see happening is that we're moving out of the window. The operator, if he's smart, adjusts his speed before, and, if he's not paying attention, he adjusts his speed afterward, to bring welding conditions back within the welding window.

But all resins are not alike. Another graph (Figure 8), illustrates the same wedge temperature, same conditions, but a different material. You see that the weld window has changed considerably. It has changed shape, slope and size. All materials do not weld alike. Engineers are specifying materials; they are talking about practical things like multiaxial tensile friction angle, stress-crack resistance, and a few other things of questionable value like melt index and OIT. Then, to cover themselves, they say things like "In welding, you will make a certain weld strength, with no incursion" without ever considering the weldability of the material. I'm not really sure if "weldability" is a word or not, but it certainly is a concept, and it's a real one for the people out there in the field. When we are designing and specifying materials, if we really do want to get installations with zero failures all the time, we have to make sure that the material we're using is easily welded with the equipment that we have, or we have to drastically change our equipment.

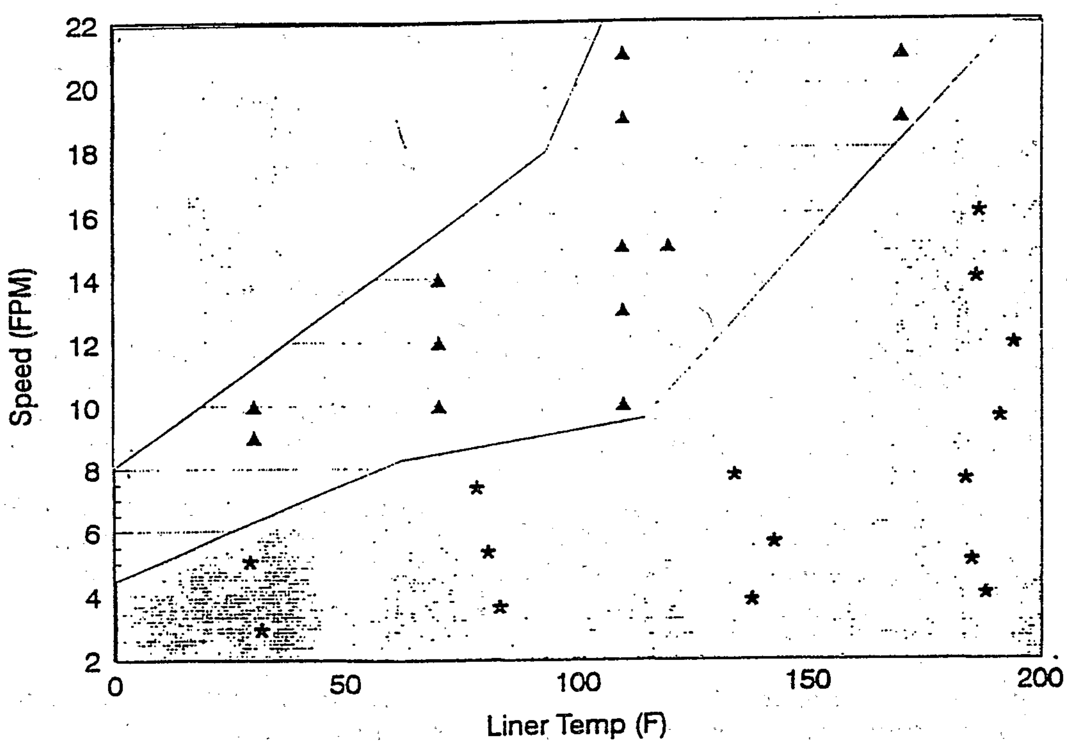

Figure 8. Welding window from real data for Resin B at 750°F (399°C).

To show also the effect of other variables, this is Resin B again, except with a higher wedge temperature (Figure 9). The welding window has moved, and is no longer very suitable for welding hot liner. However, if you were forced, say, to weld liner down around 0°F, you can see an opportunity in the welding window.

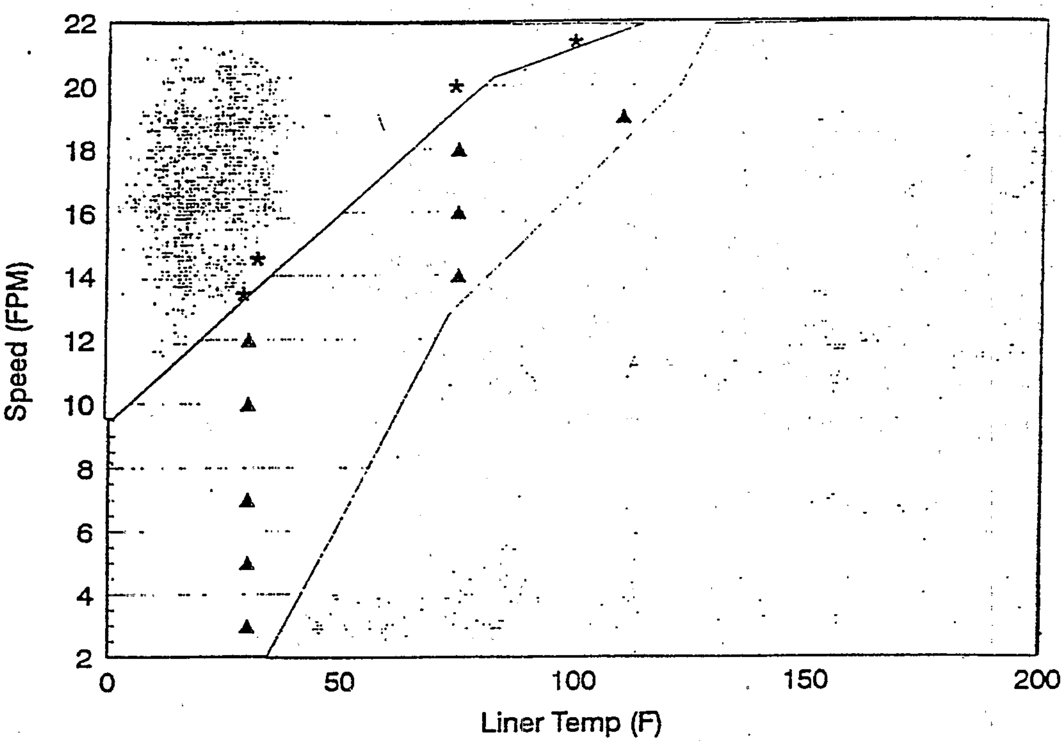

Figure 9. Welding window from real data for Resin B at 850°F (454°C).

For data acquisition wedge welders, we are also proposing speed as a controlled variable. We think that speed should be varied according to liner temperature. On Figure 10 these lines are idealized lines. They show, for instance, that for the line for 80-mil (2.0 mm), if it is 100°F (38°C), you run it at a certain speed. You would program this function into your computer, into your process control welder, and then let the computer adjust the speed of the welder based upon the liner temperature. If the operator switches over to 60-mil (1.5 mm), he adjusts his speed upward to the 60-mil (1.5 mm) line, and away he goes.

We monitor weld speed. If all things are going well, the weld speed is constant. Note in Figure 11 that there is a little noise in the data or in the actual speed of the equipment. Sometimes it becomes interesting when you get to the end of the seam and find something like Figure 12 and nobody changed any of the controls. Nobody noticed that the welder changed speed. This is one point in favor of data acquisition.

Figure 13 is a little bit embarrassing. When we first set up our lab welder, we got some pretty ugly curves for roller force, the bottom one here being the wedge roller, sheet to wedge, the other being the drive roller. We were all a little perplexed at what was going on. It is amazing what can happen when the machinist does not make round wheels or at least does not put the drive shaft in the center of the wheel. Of course, Figure 14 is what it is supposed to look like, and that's what all of our welders do look like.

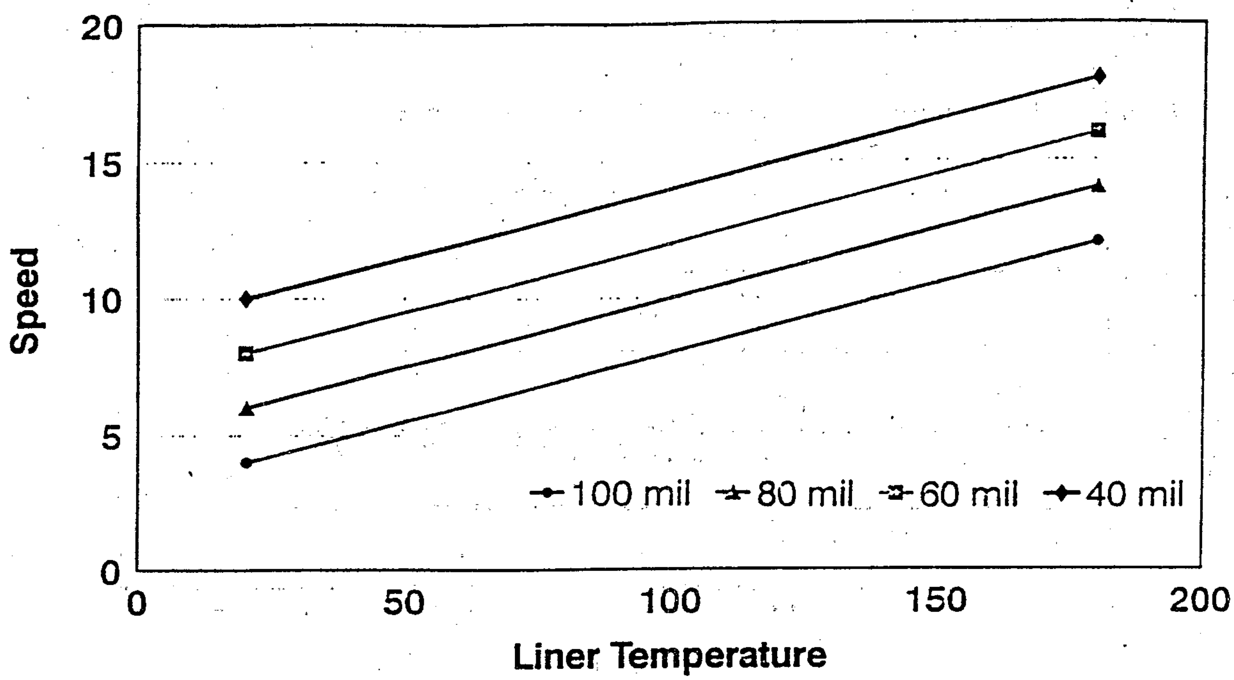

Figure 10. Welding speed as function of liner temperature for different geomembrane thicknesses.

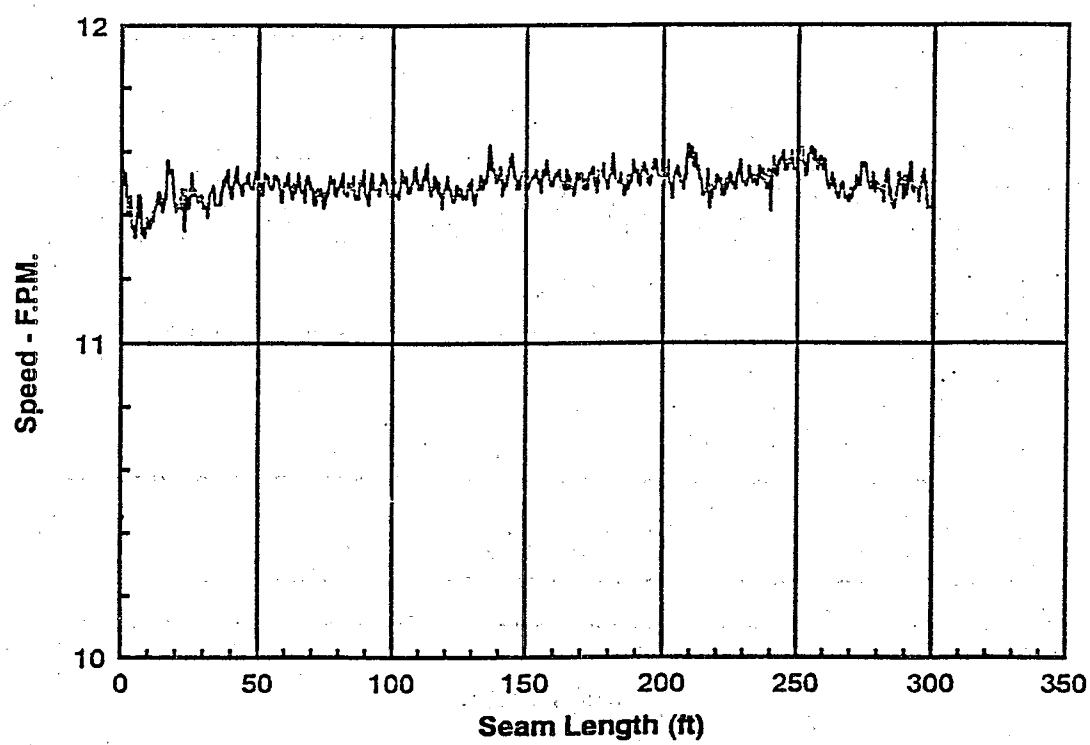

Figure 11. Graph of welding speed vs. seam length during normal seaming.

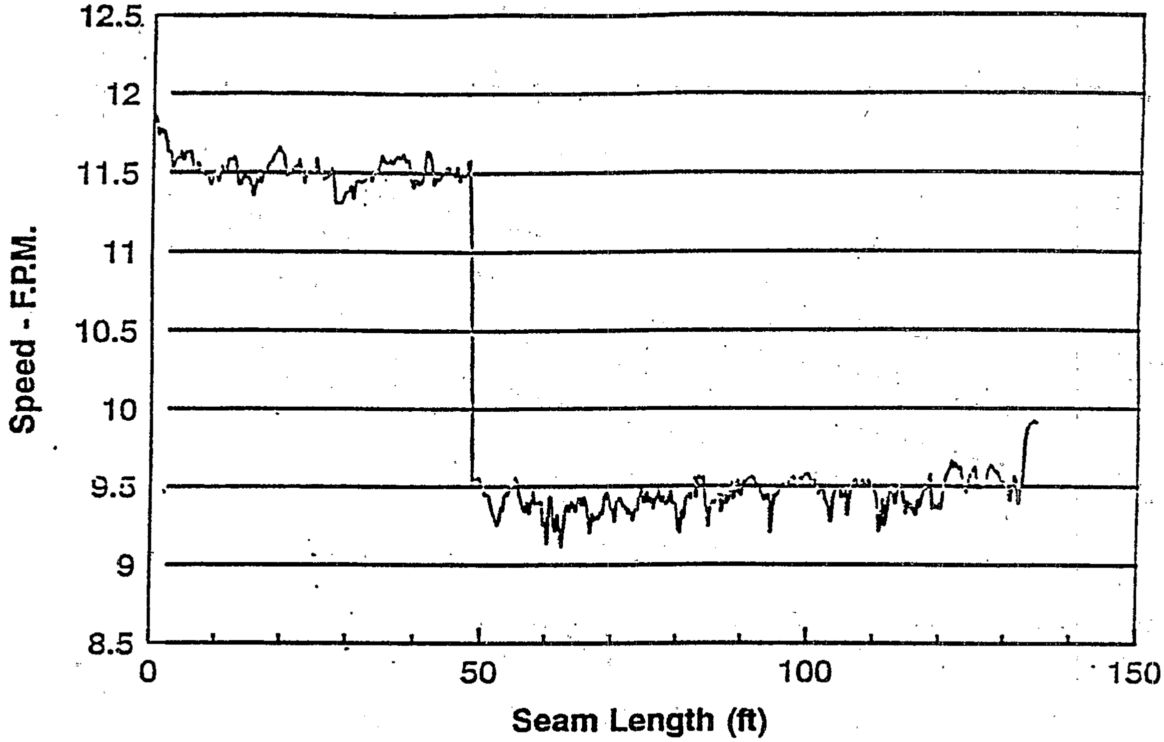

Figure 12. Graph of welding speed vs. seam length showing dramatic uncorrected change in speed during welding.

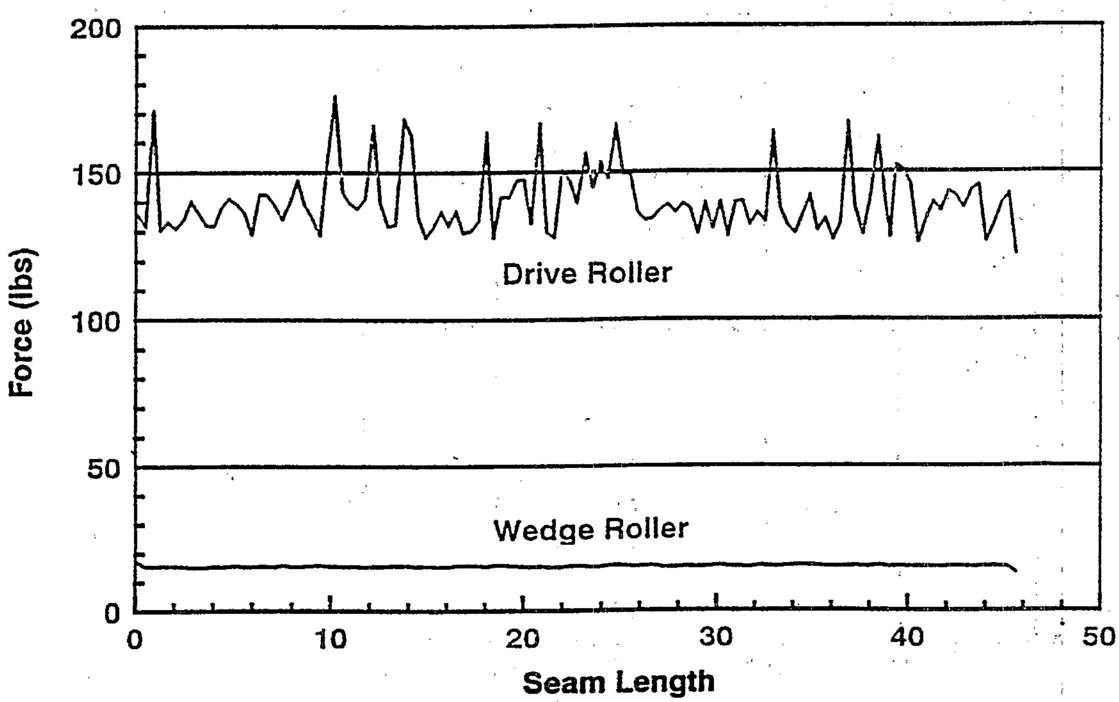

Figure 13. Roller forces vs. seam length; with defective drive roller.

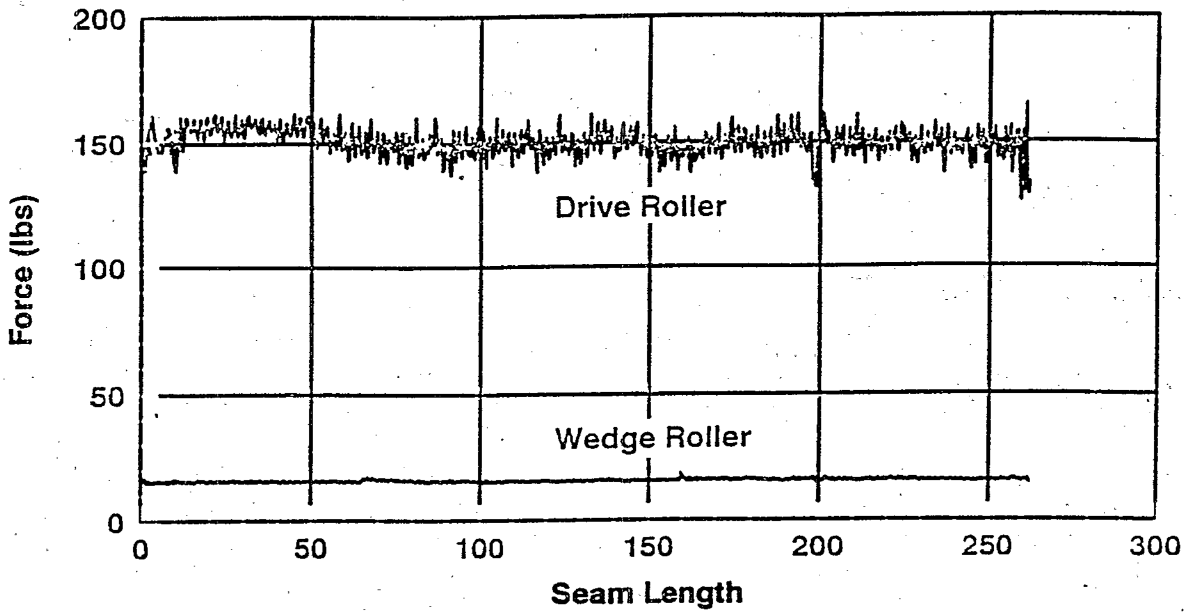

Figure 14. Roller forces vs. seam length; normal curve.

What are we doing with data analysis? Obviously, the first thing it does is offer onboard display or a printer onboard to generate the data. We can then see what's going on with a lot of variables at any given time. Alarms can let the operator know when things are going astray. As far as looking at the entire scene, we can download it to a computer, and play whatever number games are desired. Or a graph can be printed from a separate computer or directly from the welder. And data can be stored as raw data, graphs on paper, disks, or tape.

I want to re-emphasize again that we embarked on this as a project research effort. We're still looking at the benefits of regular production process control welders and data acquisition welders. We're looking for fewer failures, which is going to save money for us and the owner. Better documentation and more information, which hopefully leads to fewer destructives, are two of the points that I am really highly supportive of. I don't like cutting holes in the liner. If we can use supplemental information to go to variable sampling rate and still have the comfort that we can space the destructives out more and more, I think it's a great thing to do.

In talking to Mark Sereaci a couple of days ago, he said he likes the data acquisition welder because it frees up his CQA personnel. Right now he feels that his CQA people have to be sitting there looking at the welder, whereas, with data acquisition welders, they can look at something else that is important, or they will watch more than one welder at once. Then they can come back and take a look at the data and feel that they know what went on.

Also, it helps us analyze problems. If you do start having problems. If you start failing some welds, you've got some data to help determine if any of these things caused the problem. And if the data say yes, you've found the problem. If the data say no, at least you have eliminated them, and you can look at other things.

I feel some of the welding equipment is a little archaic and that we should be trying to improve our equipment. A quality mentality is going through the world. The data acquisition process control wedge welder is more in line with the quality mentality that is taking place. And overall, it provides a better image for the geomembrane-lined systems and the people dealing with them.

National Seal is building more research welders. They're about finished and we will be using them. We will be gathering data, analyzing the data, and evaluating whether we want to make process-control data-acquisition welders the norm. We will report back to everybody at the Geosynthetic Research Institute (GRI) Conference in December.

<u>Jerry Fisher -- Poly-Flex</u>

About 1979-1980, when I was still with E.I. duPont, a fellow by the name of C.B. Mitchell, who was construction products manager, and myself, put together a wish list for a field wedge welder. We started talking to Pfaff in Germany and provided them with seed money to develop the first wedge.

I only bring this up for one purpose. I had the dubious distinction of using that hand-held welder in the field and, compared to what we use today, you'd be amazed at the progress in technology. The concept is certainly a win-win situation. Everybody benefits if we can make it a practical unit. The question is how badly do we want to do it? With the talent that I see here today, there is no question that it is possible.

The problems will not be in the ability to apply the technology in a lab, but the practicality of using that technology in the field. I'm sure all of you who have done construction quality assurance (CQA) have watched the operator physically abuse the welder because it got stuck on a fold or something. So we will need a training program to retrain the operators that are using the equipment. The design of the sensors will have to be adjusted, not only for thickness, but for changes in temperature. We'll probably have to see an increase in the sidewall thickness because when you (which you shouldn't) run the wedge through a T-seam, you are applying a stress at a very high temperature. That metal will eventually stress-fatigue and warp, thereby throwing the adjustments of your sensors out. You can spring-load them and everything else, but there will have to be a general increase in maintenance or it could be a heavily-maintenanced item.

If we cannot design the equipment to be practical, and we end up spending more money than it's worth, in maintenance and repair, then we have defeated our whole purpose in the concept. It will require in our research and development that we segregate the parameters as we look at them.

We can dramatically improve the performance of the unit if we simply mandate that, regardless of the surface condition of the substrate, we utilize a slipsheet that would aid and abet the temperature of the bottom sheet. For some time, CQA manuals would say, well, you can look at a sinusoidal wave pattern, and that would indicate the credibility of the seam. Not so. You must raise the bottom sheet up and look at that. That is the indicator. It is the ability to get both sheets that will determine the quality of the overall seam. You can do it with one, but it will take a lot of field training and a lot of work. We can do it. I'm sure we can. I know that from past experience. But we are going to have to identify the parameters in their proper perspective before we start. Otherwise, we'll be spending a lot of time trying to figure out how to change the control unit to compensate for mistakes that we are making during the installation itself. Thank you.

Bill Walling - SLT North America

Before I start, for those of you who don't know who I am, I came to SLT about five years ago from another industry. The interesting part of it was, after I'd been there a few weeks, I found out that all of you guys were doing the same thing I had been involved in about 30-something years ago in a manufacturing research and development (R&D) effort when I worked for Shell. My first involvement with the wedge welder was about 1955. We had a joint effort with Grifolin and Shell Manufacturing to look at lining ponds. We developed a wedge welder that was a little bit different than we are using now in that we used it in-plant and we pulled the sheets through the welder instead of having the welder pull itself along the seam.

I came to SLT as a consultant with the assignment to design a new wedge welder. It turned out that I have never spent a great deal of time working on that, but the company has spent quite a bit of time working on it. More than five years ago, we were interested in the kinds of things that we are talking about here today. We have done a certain amount of work. We have built several machines. We have been looking at these welding window bubbles that we're talking about here this morning.

We have not been able to put this together in a manner that we felt bought us anything. We have felt for two or three years that there was a certain amount of pressure to do this, so we have been looking at it a little more carefully. More recently we have been hearing things like we heard from Gary Kolbasuk this morning. I would like to say that before we proceed in a very comprehensive manner, let's think about what we are really doing. The six parameters that are generally talked about here are probably the best controlled parameters that we handle in this business now. They are very important. They are necessary to produce good seams. They are the basic factors that define the welding window, but there are many more factors that Gary pointed out, geomembrane composition for instance. I'm sure he was talking about variations much more minor than the difference between high density polyethylene (HDPE) and polyvinyl chloride (PVC) for instance.

(Mr. Walling read the following paper, which he authored.)

AN EVALUATION OF PROPOSED ENHANCEMENTS FOR GEOMEMBRANE SEAM WELDING RECORDING CAPABILITIES

Before we go forward, let's think about what we are doing; let's be sure we are on the right track.

The several recording capabilities currently considered for general application to membrane seam welding equipment are (typically):

1. Air temperature
2. Geomembrane temperature
3. Wedge temperature
4. Nip pressure
5. Welding speed
6. Operator identity

These are important parameters in relation to consistently producing good seams. However, they may already be the best controlled of the many parameters that define the window of acceptable welding conditions for any specific circumstance.

More importantly:

1. There has been no demonstration that the above factors are those that cause the majority of unacceptable seams. In fact, my investigations indicate that they are not the factors generating the majority of seam problems.

2. The window of welding success is not only large, but affected by many factors in addition to the ones currently considered for recording. There has been no definition of how to combine and evaluate the proposed records to better define the window of welding success. If one parameter changes, what combination of the others must be adjusted? What relationship must be maintained to assure success? Frankly, we do not know.

3. At best, recording equipment such as that currently discussed might be economically viable for gathering some of the information that will lead us to improved seaming success ratios. They will not in themselves provide that success. We are defining an R&D information effort rather than a working technology. Is it reasonable or practical to promote an industry-wide, totally comprehensive effort to collect information that will cost the geomembrane industry between $3,000,000 and $6,000,000 before better definition of the true problem causes is made?

4. There may be other more straightforward and more cost-effective ways of not only collecting information that will lead to improvement, but that will provide some improvement in the process.

   My investigations to date seem to point out two particularly important items:

   a. Most extensive seaming problems, or projects with high seam quality control (QC) failure rates for seams produced by competent technicians, cannot be directly related to the parameters currently considered for recording. Therefore, the recording or eventual enhanced control of the currently considered parameters will not eliminate the most frequent and serious seaming problems if my observations are representative.

   b. Prompt continuous tracking and summary evaluations of the data already collected for many, if not most seaming operations, has significantly reduced the seam failure rate resulting from the parameters currently discussed for recording, i.e., more attention to both operator and equipment performance seems very effective.

      The end result information is already available if we use it.

      Constant, up-to-date real time tracking of the seaming success (or failure) rate for each seaming operator and each seaming machine has been demonstrated to enable attainment of destructive weld QC test failure rates on the order of 1 percent* or maybe only 10 to 30% of the average specimen failure rate prior to such tracking. This success ratio, of course, does not apply directly to projects presenting other seriously undesirable barriers to welding success. Adverse site conditions appear to cause many more problems than welding machine controls.

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* Based on yield and/or tear of the parent material after attaining the specified load prior to weld separation.

5. More complicated equipment with more data to evaluate may exceed the capability of most welding technicians.

a. Prompt analysis of extremely detailed information is time-consuming and may not be productive considering the size of the successful welding window. It may be more than a welding technician can provide on a routine basis. Failure to utilize the information promptly would also create a highly undesirable situation. Successfully maintaining an automatic detailed record of predetermined welding parameters may (will most likely) temporarily provide a false sense of accomplishment. We do not know what combination of these parameters assures welding success for each change of the actual field situation.

A series of welding trials conducted by SLT demonstrated a large window of welding success for the parameters currently considered for recording under most otherwise reasonable and constant conditions. However, a significant shift of definition for the window may occur when other variables such as geomembrane materials and ambient conditions change. We were unable to define a consistently successful set of conditions for wedge temperature, nip pressure, and welding speed without conducting trials to allow for the other specific variables for each situation.

b. Maintenance of the equipment may become an undesirable larger problem.

c. Installation specification writers and QA inspectors will be hard pressed to predefine the acceptable range of the parameters recorded. The installer and the seaming technician will then have their ability to react to site conditions restricted and conflicts over responsibility for success or failure will arise.

This then takes away from the operator's ability to use his skill and experience (craftsmanship) to accommodate the specific site environment at hand hour by hour - day by day.

6. The installation of recording equipment as currently discussed does not provide a significant probability for assuring improved success ratios. Nevertheless, it will be very expensive to implement throughout the industry.

Some efforts estimate that there are between 1,000 and 1,500 welders to be replaced or converted. At an estimated cost of $2,500 to $4,500 per machine for recording only. The industry will have to absorb between $2.5 million and $6.8 million for conversion. That is a lot for the recording of information that has not been demonstrated to produce improvement and might cause more problems.

I would define a "smart" welder as one that not only collects good useful information, but is able to manipulate this information to produce a useful end result. The indiscriminate acquisition of information does not necessarily provide useful knowledge.

The usefulness of knowledge may not apply to all environments or be competitive with other knowledgeable techniques producing an equivalent end result. Information in itself does not provide control. The information we currently propose to collect may not be the information needed for improvement.

Although I agree that improvements in geomembrane heat seaming technology are desirable, the indiscriminate application of additional recording technology to existing equipment, just because it is available, has a very low potential for producing a significant improvement in the end result. We have not defined a reasonable justification for initiating a comprehensive effort to use the proposed records to generate a significant improvement of seaming success.

I believe that a much better investigation of the usefulness of the information we propose to collect is needed <u>before</u> we attempt to collect it on an industry-wide comprehensive scale or promote it as a significant improvement to existing technology.

In fact, in my current opinion, the odds are that a concentrated effort to equip most or all of the current geomembrane double hot wedge equipment with more recording instrumentation is more likely to <u>delay</u> real progress and to inhibit real improvement in welding success ratios, than to significantly assist in attaining more consistently successful seams.

<u>Finally</u>

Our geomembrane industry needs to strive to improve the seaming process. I do not wish to jeopardize progress in that direction.

However, industry-wide adoption of the recording capabilities proposed just because the technology is available is not an efficient way to proceed. The cost is high and the potential for success is low. We could end up spending $6,000,000 to look bad.

SLT proposes that we establish a jointly funded/supported task force to investigate and better define the causes of inadequate seaming procedures. I believe that improved assurance of technician performance and uniform seam evaluation procedure is worthy of attention equal to that devoted to the welding machine.

I suggest that the task force consist of representatives from each of the following:

1. The EPA
2. GRI
3. Each of the geomembrane manufacturers

I propose that this group meet and provide an action plan for distribution and approval of the sponsors by June 28, 1993.

In the interim, I propose that the most effective, most logical step toward continuing improvement would be to encourage improved analysis and evaluation of current up-to-date summary records of each welding machine and operator. This should not only provide a better direction and a greater potential for designing successful improvements, but a better success ratio in the interim provided that it is also appropriately correlated and judged with respect to the environmental conditions and circumstances associated with the installation.

<u>Fred Struve -- Gundle</u>

I thought I'd start off making a point in neutral territory -- an internal combustion engine (Figure 15). For those of you who are not all that familiar with an internal combustion engine, a type of lifter valve lets in the air-fuel mixture and exhausts it. It is opened and closed by a camshaft, which moves up, moves the rocker, and comes down and pushes the valve down. In automobile engines, they always start off cold, and, as they heat up, the metal expands. If you don't have any clearance somewhere in the valve train, as the engine heats up, it will all expand and will partially open the valve and the valve will burn.

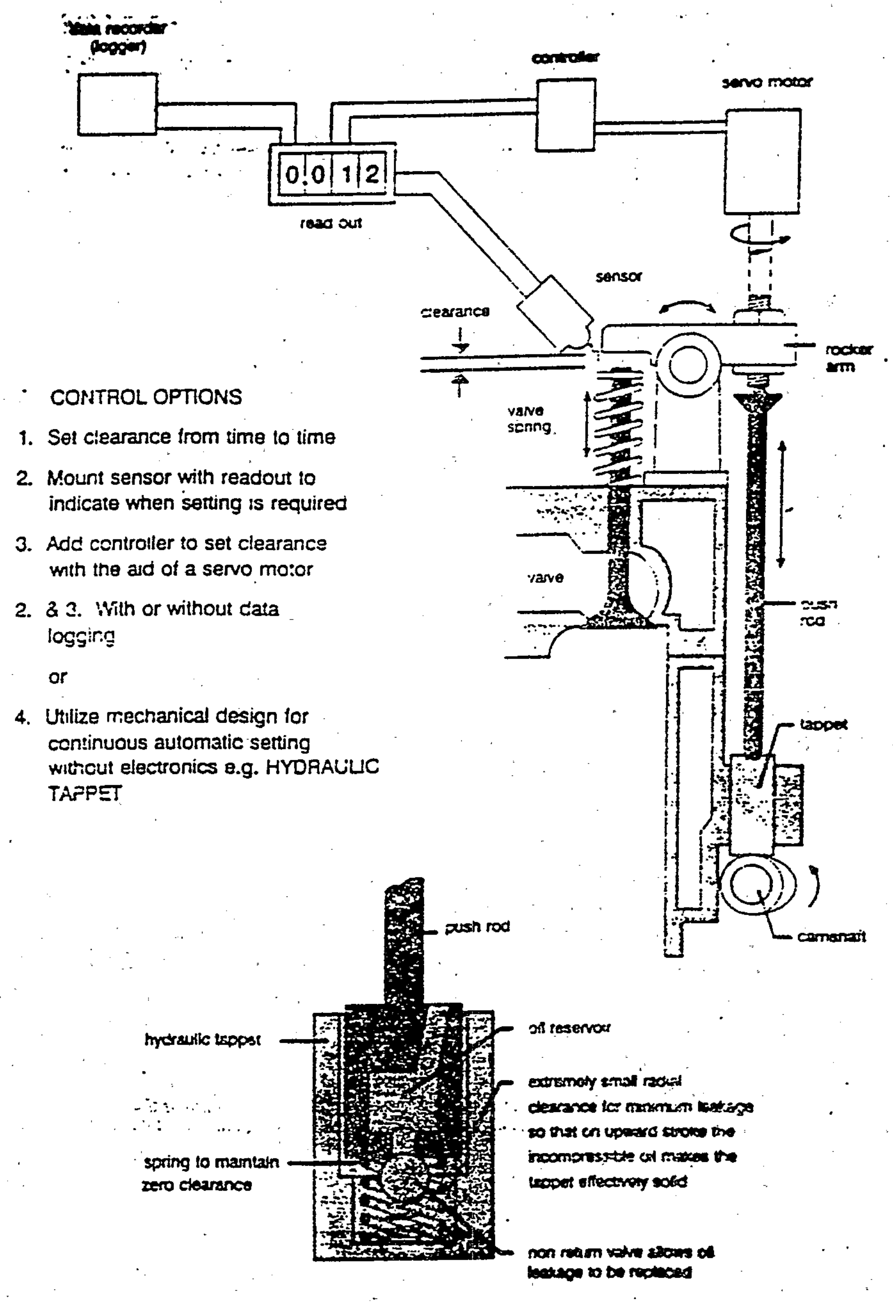

Figure 15. Internal combustion engine valve mechanisms.

The traditional way of coping with this has been provision of a cold clearance setting. You include a feeler gauge and undo the lock nut and adjust the screw on the rocker arm. Set it to the required tolerance, clamp it down, and then after you drive 15,000 miles, you check it again, unless it becomes noisy. That's ne of the control options, just to set the clearance from time to time. This type of system has been used in millions of automobile engines over many, many years.

There is of course a second possibility, and that is to mount a sensor of some sort which will measure that clearance. You could simply have a readout there and be able to monitor what that clearance is and, at an appropriate time, when it goes out of tolerance, you stop and reset it. You could do that with data logging. You could record that information if you chose to. You could also put that information through a controller and add a servo motor and have a closed-loop feedback system. Those are all possibilities.

However, what somebody very smart in the automobile industry figured out is that there is a better way to do this, and that is using what they call a hydraulic tappet. In a hydraulic tappet, you replace the little solid tappet with a hydraulic tappet. It is a two-part system, and it has a little spring in it which pushes a piston up. Whenever this is not on the lobe of the cam, the spring is strong enough to maintain the clearance at zero, whether its cold or hot. The hydraulic fluid in there is incompressible, and when the cam pushes the tappet up, the clearance between these two parts is very tight. The amount of oil that has leaked during that rapid acceleration as it moves up the lobe of the cam is negligible. In effect, the tappet and pushrod are a solid member as they accelerate up because the oil is incompressible. As they come back down, if there has been any oil loss, the oil comes back through the little nonreturn valve.

The hydraulic tappet mechanically gives you zero clearance irrespective of temperature, how many miles you have on the car, or whatever is happening. In principle, and its the same principle that we have with any device, including wedge welders, you've got to make the initial setting, reset it from time to time, and maintain it well. You could add all of these elements. You could add any segment of them, or you could come up with a smart mechanical design which serves the purpose. This has really been a brilliant thing, and there are millions and millions of such units in service, keeping control of your process, automatically, without any electronics.

With our geomembrane wedge welder we have tried to pay a lot of attention to the mechanical design and to make as many things process-controlled automatically (Figure 16) as possible. The first thing that seems to be uncommon in our wedge is that it has flat surfaces. A flat surface seems to me to be more natural than a curved surface. I've heard people describe the curved surface as pretty much the natural way that the material comes over it. I can see that would be true on the upper surface, but on the lower surface, it's going to bag down and you have to push the sheet up against the wedge in any case. So the bottom isn't really as natural as it would appear to be. Also those surfaces are slightly different. The amount of bending force you require is different if you are using a thicker geomembrane. To get 40-mil (1.0 mm) to comply across a curved wedge obviously requires less force than 120-mil (3.0 mm). We decided to go with a flat wedge. We also made the thing slightly isometric because there didn't seem to be any purpose in raising the upper sheet any further than you need to. What we've done is try to keep that upper sheet down as close to the ground as possible.

We made the wedge and the nip rollers pivot about the same center (Figure 16). It also is the driveshaft which takes the power to the lower roller through a series of shafts and gears. The wedge is fixed in radial relationship to the wheels, and it is allowed to float to a certain degree between them. The purpose of this is that when the sheet goes through this machine, where it is touching the wedge is the same irrespective of the sheet thickness. If both sheets were twice as thick, the only thing that would change is the wheels which would move apart slightly. Also this wedge is free to float. It is not spring-loaded in any way. So it assumes its position of minimum energy, or minimum force. There is no way that this wedge can be pushed harder up against the upper sheet than the lower sheet. It is automatically self-balancing.

All drive elements are internal shaft/gear/sealed ball race driven

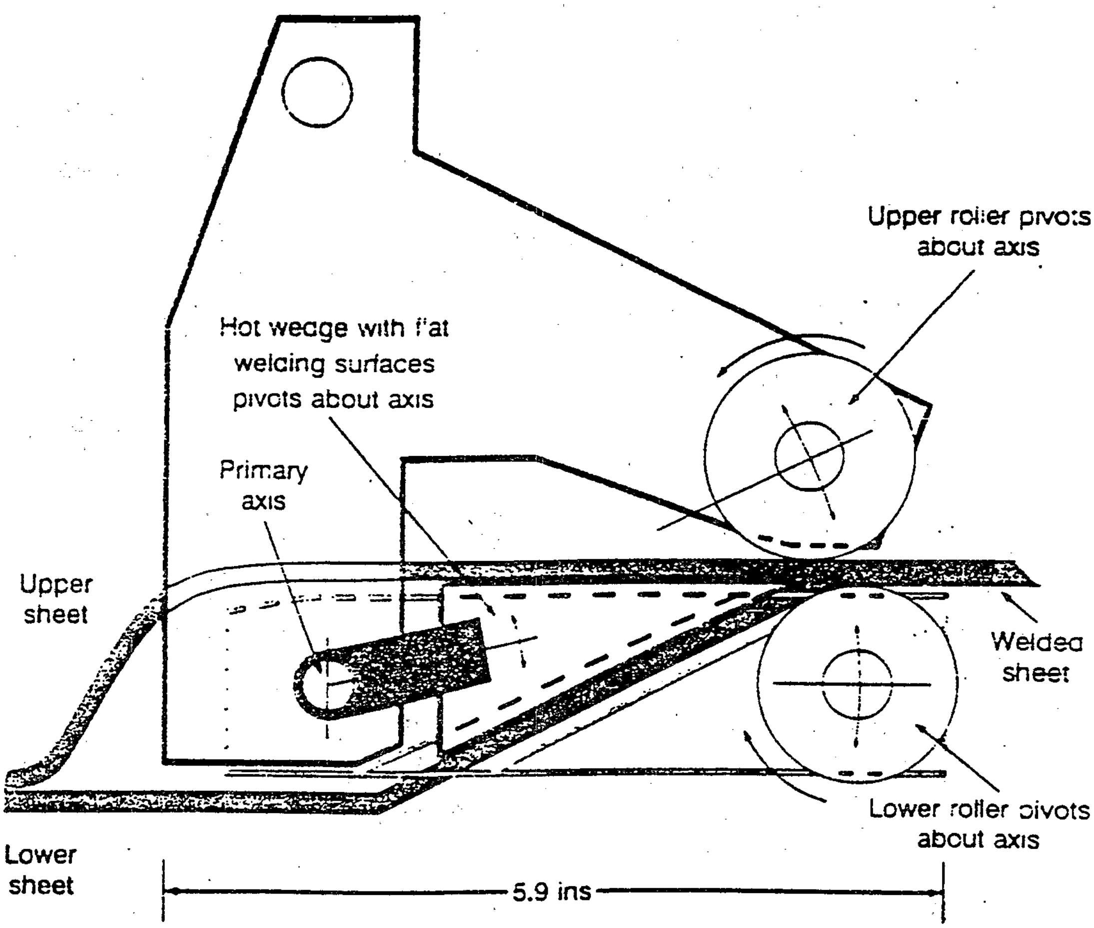

Figure 16. Primary elements of Gundle Wedge Welder.

The other point about doing it this way, or all about the same axis, is that the wheels obviously move on the same arc. The nip point is also exactly the same.

We try to package this into as small a machine as possible, and Figure 16 is pretty much a scale representation. You can see that the length of the machine is just 6 inches.

To get the sheet to comply with the wedge, we chose to use flat plates, again because we believe that going over the wedge flat is a natural thing to do. We have what we call the sheet control plates and a yoke which holds that. This yoke (Figure 17) is on bearings, and this whole yoke slides over the roller shaft. Radially, with respect to the nip rollers, the yoke is always in exactly the same position. It is spring-loaded with a torsion spring, which has a very low spring constant. The idea of the spring constant being low is that for any angular change in position, by having thicker sheets for instance, it may move three or four degrees down, further away from the wedge than it was before. With this type of spring constant, the difference in force is trivial. So in fact, like the hydraulic tappet in an automobile valve lifter, we have an automatic control of the force.

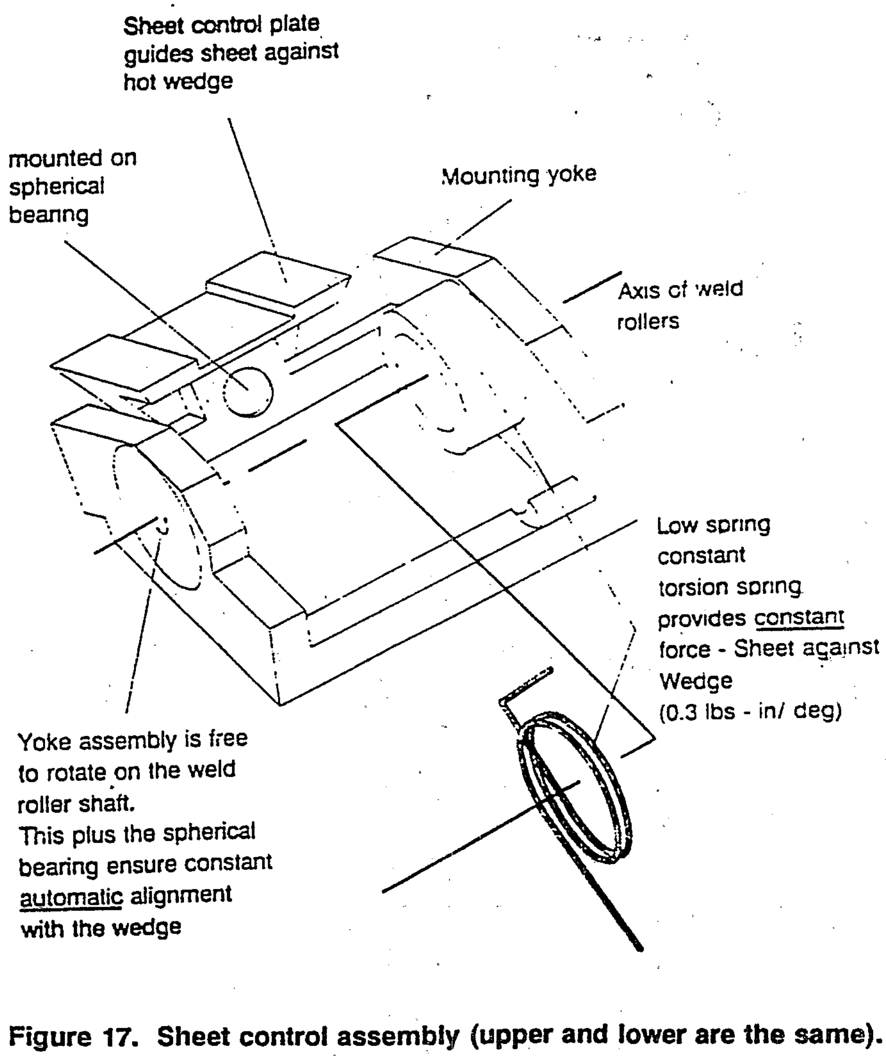

Figure 17. Sheet control assembly (upper and lower are the same).

I forgot to mention what we've done to load these two wheels, to create these nip forces. We've used a very low spring constant main spring, so that any changes in thickness of the sheets create the minimum change in nip roll force.

Our production machine weighs 29 lbs (13.2 kg). Everything is shaft and gear-driven. The motor goes into a series of shafts, and all of the shafts are internal with beveled gears and sealed bearings, again to try and keep the whole thing as simple as possible for the operator.

We have tried to make it as much as possible automatically process-controlled rather than adding any electronics on to it. We're not scared of the electronics. It is really a matter of principle.

We had one box built for us, which is a completely integrated control box with a smart card memory system. The box houses the complete setup of speed control, temperature control, force measurement, etc. We have chosen not to go with it, because we felt that it was a little more difficult to maintain than we would be comfortable with.

We chose to use more commercially available, off-the-shelf components. We have a temperature controller which we can program and a closed-loop feedback speed control system. We hadn't intended to include the sheet control and computer- controlled possibility of adjusting speed vs. sheet temperature. We're not totally converted yet, but we decided it would be better to include the capability so that if we choose to use it, we will have the electronics.

In addition to the commercial, off-the-shelf controls with which you can operate the machine, we've added a custom board which is the power supply and the signal conditioning for all the functions to convert all those signals that we have to 0 to 5 volts. We've chosen to keep our control box and the measurements separate from the data-logging function. We then had a data logger developed, with surface mount technology to keep the weight down. It has the capability of logging eight channels, and we also have paused in the development of this one. We're adding into this the capability of adjusting speed vs. any of the channels that we have, particularly sheet temperature. This logger has a computer in it, a very powerful computer. It also has all of the signals in it, so we are able to send a signal back to the speed controller to go up or down according to whatever program we put into it. We are actually set up to go the whole way if we need to.

It's a very open looking design. Nothing is buried, which does seem to help.

A simple temperature controller can be programmed to behave differently from the standard way. It has certain limitations, but we felt that those limitations were worth having, based on the control we could get. On Figure 18, note that the start of the weld and the time in seconds before the weld indicate how the temperature is moving about, before we actually put the wedge into the seam. These wedge welders do have a problem, which Gary Kolbasuk alluded to as well, and that is when you are not welding they have tremendous heat capacity. They respond very rapidly the moment you put them into the sheet. You have a tremendous heat load and now they don't have quite that much, so the response becomes much slower. But Figure 18 shows what we achieved with the temperature controller. You can see here that we are swinging within a total band of less than 5°F (2.8°C). We're swinging plus or minus 2.5°F (1.4°C).

One thing with temperature control in any system is that it is voltage-sensitive. Typically, your computer is going to set up to give the heat as 50 percent of the power at set point. As the offset gets worse, the computer will add more power. At a certain point, when the heat is on 100 percent of the time, and you cannot give that heater any more, the voltage drops, and the power to the heater drops. You can get to a point where the computer is giving it all it has, but there isn't any more left because the voltage has dropped so much. So voltage is an important thing to watch on these machines. The computer controls the temperature within a certain band, but if the voltage drops too far, it's impossible for the computer to give it any more.

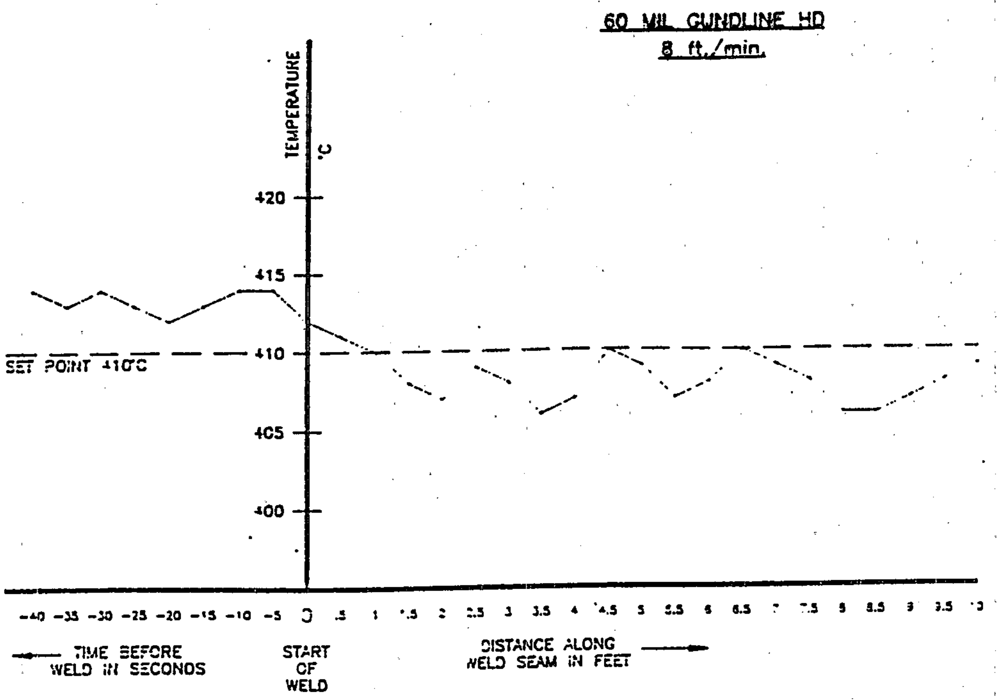

Figure 18. Wedge temperature with specially programmed controller.

When we made our first control box we found that it was like having driven with your windshield iced up and suddenly you got it clear. You could actually generate some of these welding curves and we could repeatedly go back to them. Over the summer we had Greg Corcoran doing some research work for us and he welded about 6,000 ft (1,965 m) of seam and generated a large chunk of the three-dimensional welding bubble that we were looking for. When we saw what that was, we found that in all cases the outside seam would fail before the inside seam when we got to edge of the bubble. We found that we could go back repeatedly to a point on the outside of this envelope and get the same results.

For the first time we really knew where we were on one particular condition. What we decided then was to stop generating the bubble information, see if we couldn't even the tracks, and make some changes to the machine. We spent probably three months making detailed changes to the mechanical welder, making geometry changes, until we found that we had the tracks evened out, and that we could do everything and get back to the same conditions. We've done that now. We are retrofitting all of our machines at the moment mechanically, and we are also adding that box to it. The result is that now we have a machine, which, because of the fact that we put eyes on it, because we cleaned that windshield, we were actually able to make some serious improvement of the mechanical components.

Figure 19 shows the result that we have now at 70 lb (32 kg) nip-force. We've got the wedge set up so that we have about a 10 to 1 speed ratio, and we don't see any merit in trying to weld faster than about 18 ft (5.9 m) per minute. We think that is already very difficult to control.

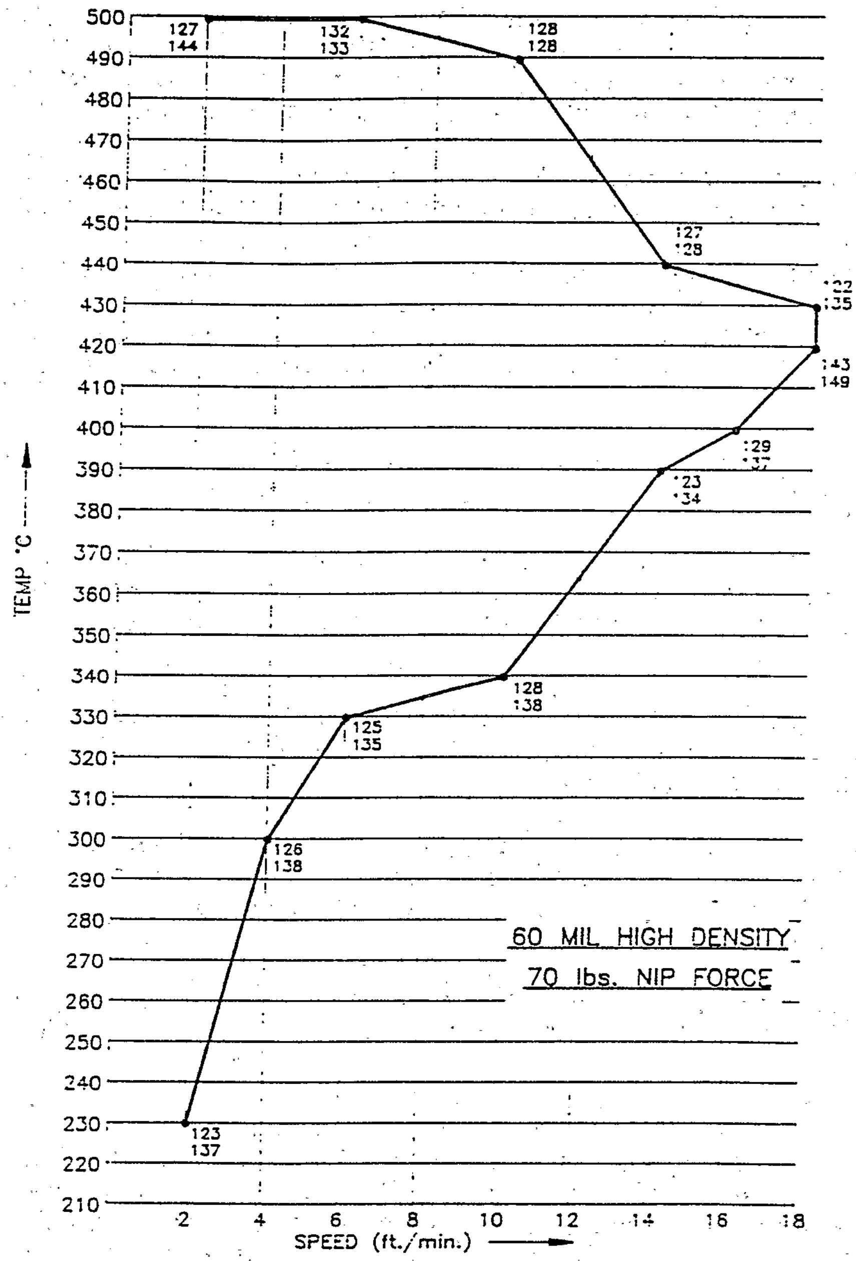

Figure 19. Peel strength values (small numbers at points) vs. welding speed and temperature for 60-mil (1.5 mm) HDPE.

The small numbers on the curve are the peel values in pounds per inch that we are achieving, outside track and inside track. The difference between this window and the window that we had generated on our machine, as it was before we cleared the windshield, is significant. Especially, the peel strength values are significant. I think most of you are familiar with the numbers that we typically look for on 60-mil (1.5 mm) geomembrane, and you'll see that these are really something to be pleased about.

Figure 20 shows the same curve except now with 40-mil (1.0 mm) which results in a larger window down at the right end. These are enormous temperature ranges. Here you see that it does drop down on the thinner sheet as you are going slower and as temperatures are raised. You soften the material and you melt right through it. It's not unexpected as you go into the thicker sheets, that it doesn't drop off quite like that. There's enough strength in what's left of the material that you haven't melted.

Figure 21 shows the two curves pf 60-mil (1.5 mm) and 40-mil (1.0 mm) superimposed. Again, if you look at the peel values, each data point, they're significantly higher than anything we generally achieve.

To demonstrate the self-aligning, self-process control of this machine, we set the welder at 70 lbs (32 kg) force, 380°C (716°F), and 10 ft (3 m) per minute, on 40-mil (1.0 mm) HDPE. We then welded 60-mil (1.5 mm) without touching the machine, without adjusting anything at all, not even showing it a screwdriver. We also welded 40-mil (1.0 mm) VLDPE, and these three welds were, by any of today's standards, perfect welds.

We chose to let the computer and the data logger drive the printer, so that on site you wouldn't need a personal computer. Figure 22 shows the type of output generated.

You have the possibility of someone stopping and starting a seam. You can only enter the seam number once in the logger. The operator can't later on do another seam at the back of the shed and say here's the results. If he does have to stop because there's a fault or a problem and start again, he gets the suffix A, B, C, or whatever.

On some long seams we sometimes start two or three welders on the same seam. If there's a second welder on the seam, he would be, he would be identified as 2, with the same letter as described previously, and on his first show would be A.

We feel very strongly that if everything is in good shape, you don't need to be recording a large amount of good information. You don't need to record every two seconds. Possibly every six feet, a data point should be taken. But if anything goes out of tolerance, that should be recorded irrespective of when it is. In this way we will save memory space.

The next item printed out is what the set points are and what high and low alarms are. The data logger has an alarm which has to be acknowledged if it goes out of range. The next thing it will do is print out the alarm log.

That's really all you need from the logger. You don't need the curves, but you also need some security. Clearly, you want to see what actually happened. You want to make sure that just because it didn't show any alarms, the machine was still working. We have chosen to do the curves of the various channels running down the paper. If using continuous stationery, this will print out, and if your seam is long, it will just continue onto the next page. The scale is always the same, because what we have seen on some of the machines that are around, if you have a 100-ft-long (30-m) seam, the curve is 6 in (15 cm) long and, if you have a 300-meter (915 ft) seam, it is still 6 in (15 cm) long. The thing just gets completely black with data points. We just decided to go with the data points and go continuous.

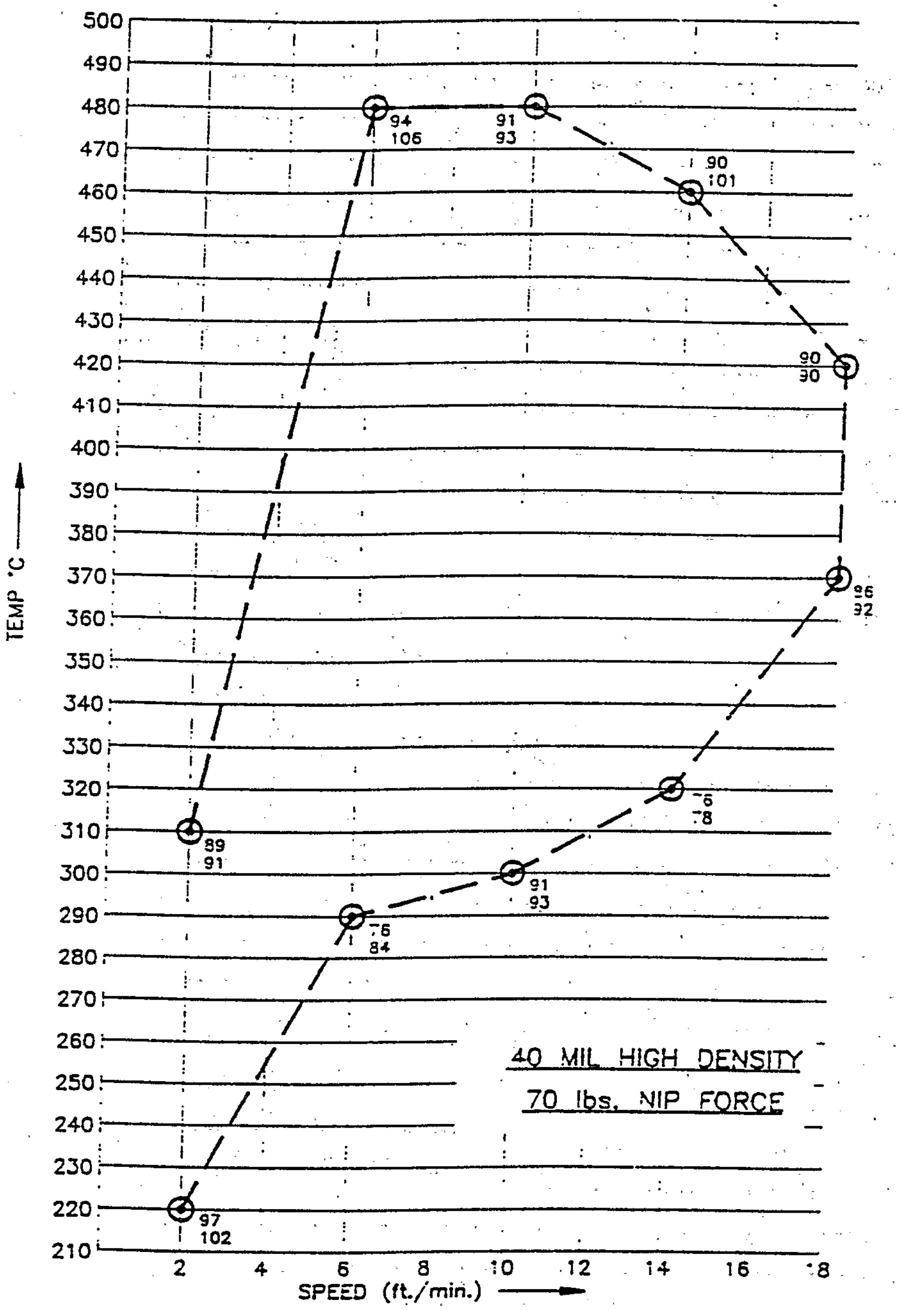

Figure 20. Peel strength values (small numbers at points) vs. welding speed and temperature for 40-mil (1.0 mm) HDPE.

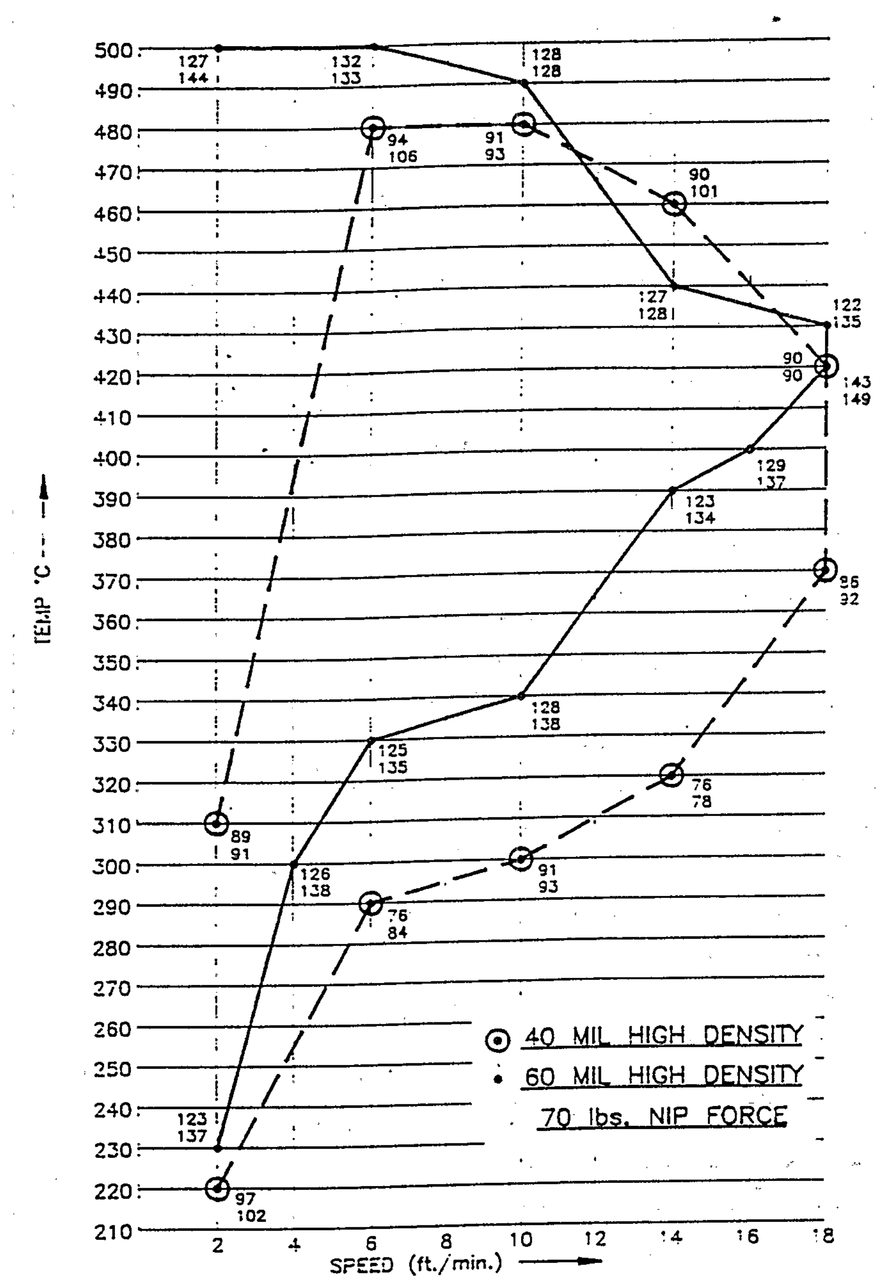

Figure 21. Peel strength values (small numbers at points) vs. welding speed and temperature for 40-mil (1.0 mm) and 60-mil (1.5 mm) HDPE.

GUNDLE LINING SYSTEMS

			DATE	:	03/17/93
JOB NUMBER	:	- - -	SEAM NUMBER	:	888899991A
TIME OF DAY	:	2312	MACHINE SERIAL NBR	:	00000001
SSN	:	217885544	DATA POINT EVERY	:	1 Ft

		LOW ALARM	SET POINT	HIGH ALARM
WELD TEMP	:	346	350	354
WELD SPEED	:	16.5	17	17.5
WEDGE FORCE	:	090 LBS	100 LBS	110 LBS
RELATIVE HUMIDITY	:	0%	NOMINAL	95%
AMBIENT TEMPERATURE	:	0	NOMINAL	40
LINE VOLTAGE	:	108	NOMINAL	135
SHEET TEMPERATURE	:	0	NOMINAL	80 (FUTURE)

ALARM LOG

1 WELD TEMP 355 AT 18 FT

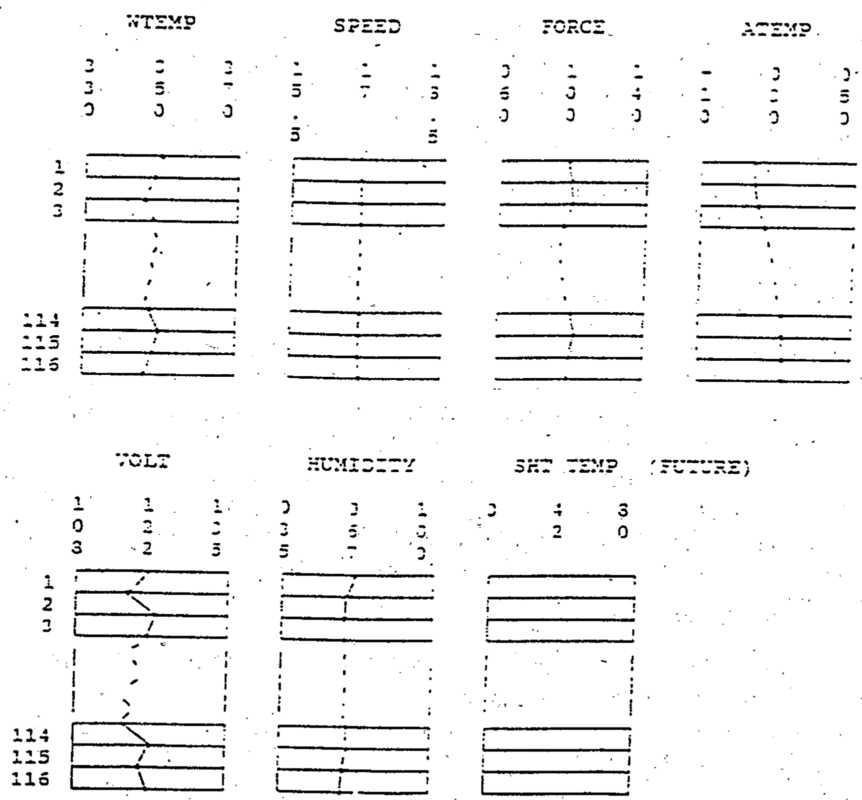

Figure 22. Data logger information from Gundle wedge welder.

We are set up to record wedge temperature, speed, force, ambient temperature, input voltage, ambient humidity and sheet temperature. If we don't like sheet temperature, it's much easier to tell you we're not using it because we don't believe there's anything in it than to tell you we don't like it because we don't have it.

We also are developing the 1994 model and I don't need to go through that. It's essentially just a later version of what we already have. The same principles apply. The front roller has been undercut so that when you are rolling along the sheet, you don't use the weight of the machine to embed dirt into the seam area. Little details like that make a difference.

To close, the points that I'd like you to remember and that I really believe in are as follows:

- Use electronic feedback control only when you must.
- If you use it, use it irrespective of whether you are data logging. Data logging isn't really that important. I agree in some way with what everybody said. Repeatability on these machines is more important than absolute parameter values. We need to hear this message early in the workshop because you need to be sure that when you say you are welding at 70 lbs (32 kg), that you are welding at the same 70 lbs (32 kg) that you thought you were welding at yesterday. It's actually irrelevant if on that machine it's 72 or 68 lbs (33 or 31 kg); these are not lab instruments and repeatability is extremely important.
- The last point which has also been well-made for me previously is that the parameter settings are only valid for the brand of machine that they are generated on. Peel strength values are obviously universally valid, but remember that we have our thermocouple positioned in a place in the wedge to give us that good temperature control. We don't have the thermocouple positioned in the wedge to tell us what the actual temperature of the sheet is before it goes into the nip rolls.

Fred Rohe -- Environmental Protection, Inc.

My purpose is to talk about some other geomembrane products, that is, other than polyethylene. I haven't been doing this since 1955 like Jerry has. I started several years ago out of necessity. We primarily do PVC, but we do some of the other flexible liners. Our interest in wedge welding was to extend our construction season, to be able to work earlier in the spring and later into the fall. Working with adhesives and chemicals that are temperature-dependent was a bit of a problem. So we spent some time with a lot of our Canadian friends who do this quite regularly: Geoguard, Solmax, Layfield. Installers who are working up in Canada pretty much take using wedge welding with PVC for granted. It's also done considerably in Europe and just like the sharing of information this morning, they shared information with us and we bought some equipment and got started.

Most of the equipment that's used on PVC is a little smaller and lighter equipment because of the flexibility of the material we are working with. But the machines are primarily the same as those used with polyethylene. It's just a matter of a little bit different technique in providing the setup and feeding the material through the equipment. To my knowledge, nobody in the PVC industry is working on developing a smart welder. I'm not sure some of the manufacturers are represented here, but my information is that developing this equipment specifically for the PVC industry is not underway right now. Primarily because there is not the demand. But I believe that a lot of the things that I've seen here this morning can be adapted to what's being done with the hot-wedge welders we use.

The hand-held welder that we use is Pfaff equipment. Often on the thinner geomembranes we will use a neoprene roller rather than a knurled roller in order to allow the material to flow through the machine without binding. Depending on the gauge of the material, sometimes we need to use a combination of knurled rollers or one of each.

One of our first projects that involved wedge welding of PVC was a project to line a canal under water. We had approximately 45 minutes to make the seam, and then the liner was put in place underwater and covered with concrete. For this particular project, we did a test strip for each seam that was made, but you could see that if you had data that you could analyze prior to going into service, you could probably be more confident in the work that is being done as opposed to testing after it is already in place.

We've pretty much gone to a double wedge, or a split wedge, as is done with polyethylene, and using an air channel test.

When we started with this equipment, we had to basically start from scratch with the settings because we didn't really have a manual to follow. We set up a 150-ft-long (46 m) seam in our plant. We set the speed at 7 ft (2.1 m) per minute. We varied the temperature as the welder traveled along the 150-ft (45 m) distance. We raised the temperature in 25°F (14°C) increments. As soon as the machine came up to temperature, we marked a section on the seam, recorded that on the seam, made 2 ft (61 cm) of weld, tested that area and went from basically at the lowest temperature with no bond to the highest temperature where we actually burned through the material. From there, we could begin to determine what kind of temperature settings to start with. We did this for the gauges that we primarily work with, which are the 20, 30, and 40-mil (0.5, 0.7, and 1.0 mm), and tried to develop a window for each. The window is basically from 225°F (107°C) to about 375°F (190°C). What we did then was start with temperature settings of about 325°F (163°C), varied the speeds to the kind of weld we needed and went from there. We saw a definite correlation between thickness and the kind of peel strengths that we could get from the material. As we began to develop data, we went back to look at what we could do with the wedge welder. When we analyzed the seam samples that we made on each seam on the canal project, we got pretty consistently, with 30-mil (0.7 mm) PVC, peel strengths in the 30-lb (13.6 kg) range.

This was a two-pass job. The first time through was kind of a learning curve for us and the technicians. When we came back with the second pass we took a look at the same kinds of numbers and we saw that we were seeing a little bit of a shift. As the technician got more familiar with the equipment, the better job he could do.

We took a group of data, over two years' worth of samples, approximately 432 specimens that we tested, and took a look at where we were failing, with both 30-mil (0.7 mm) and 40-mil (1.0 mm). We found that we were getting pretty good peel strengths, especially in comparison to the other types of welding.

Basically what we've done is experimented with using the wedge welder with PVC, Hypalon, XR-5 -- the flexible liners other than polyethylene. I believe that it's a viable alternative. It can be done. It does take some different techniques than you're used to with polyethylene, as far as how you deal with the material. We've found it to be a good process. It's doable. As far as whether the data acquisition can be applied to this, I think that mechanically it can be applied to the same equipment. Whether it's necessary is the topic of discussion today. I guess the reason I'm here is to let you know that the same thing we are using for polyethylene liners also applies to the other thermoplastics.

Just one more thing. I think this technology thing is great, but there's an old business axiom that goes "You can get it good, and fast, and cheap, but you only get to pick two out of three." We need to keep that in mind when we talk about this.

Glen Zenor -- J. P. Stevens

My responsibility is for roofing products and environmental products. We have had seven years experience in the roofing business with the technologies you are working with right now. What I would like to say from a membrane manufacturer's point of view is that I find it interesting as I become more and more involved in environmental, that everything has to be certified. Instrons® have to be certified. Welding machines could possibly be certified. Yet we are doing nothing about our work force. We are doing nothing to bring our people up to an acceptable level. If we bring our technicians, people who use the welding machine, up with respect to knowledge about what they are doing and why they are doing it, we as an industry are going to become stronger and better off.

The machine is only as smart as the person using it. We are using basically tools. And we all know that the tool is only as good as the craftsman that's using it. If you don't stop and get into a task force as was suggested, and address this situation, I think we are all fooling ourselves. We like the technology, it's important, but as others have said, we need to bring our work force up in the knowledge of what we are doing. We have to have the Instron® certified, but yet we don't have any of our work force certified.

I think we can learn from our European neighbors in that their craftsmen in roofing; and I don't know about the environmental divisions; are all certified craftsmen, and, in turn, their workmanship is great. That's all I have to say. Thank you.

Frank Sinclair -- Sinclair Equipment Co.

I'm going to spend a few minutes this morning to introduce you to the Pfaff 8365 wedge welder. This is our computerized wedge welder. It has basically three versions, our standard welder, our recording welder, and our process welder.

Some of the specifications on the 8365: 220 volt, 1000 watts, seam width maximum of 60 mm (2 ft), maximum sheet thickness of 200 mil (5 mm) plus, maximum overlap six inches, and available with solid or split welding capabilities. One feature I'd like to point out on the unit that we feel is important, is a removable wedge with temperatures of 700°F (371°C) plus. Inside of our welding chamber or underneath the machine, is the ability to pull the wedge from underneath for inspection, cleaning, and repair. It also helps to eliminate the heat rising into our electronics.

Version A of the welder is our standard welder. The welder is as we basically all know it today. Speed and temperature controls are made manually. With the base unit of the 8365 we can change our control boxes. With four anchorage points and our quick disconnects, we can remove our standard control box and install our computer control box on the same welder.

Version B is our computerized unit with printout. With this we record sealing speed in meters per minute or feet per minute, wedge temperature in degrees Centigrade or Fahrenheit, roller pressure in newtons, ambient temperature, sheet temperature, date and time, machine number, company name, operator name, seam number, and site or job. Operations can be set in English, German, or Spanish. Our preset values are entered into the machine via the key pad for temperature, speed, and pressure.

Our temperatures read out in bargraphs. With this visual readout. Once we are welding, if we go outside any of our set parameters, a visual alarm appears on the screen and a hard copy printout is produced on the printer.

The 8365 also has the capability of automatically adjusting the pressure, speed, and temperature of the unit if we experience sheet temperature changes. The seam length for reaction of the welder is approximately one meter. It takes about three feet for it to adjust itself back into its set values.

Our second system for the computerized unit is our seam system. This is our process control system. This allows data acquisition of the seam and also allows clear and easy evaluation of specific data. The seam card is preprogrammed with operator/identification, job name, etc. It is basically the size of a credit card. It is inserted in the machine and it is attached with Velcro strips. It is in about a 5x5-inch (12.7 x 12.7 cm) box. It can be removed and then downloaded on to a computer such as a laptop every evening or back at the shop location. The seam card can store up to 560 km (350 mi) of seam information, documenting all these parameters.

The entire seam is laid out on the computer or the graph. No matter if it is a 3-ft (91-cm) seam or a 500-ft (152-m) seam, we'll see the entire seam in this fashion. Our alarm with that length of seam will be much smaller. We have the ability to isolate that area of concern and enlarge it for further examination. This gives us the ability to review our data on each seam, possibly with fewer failures and less destructive testing.

That's all I have for you. Thanks for the opportunity.

__Franz Engel – Bauveg-America__

I will tell you a little bit of background about our company and our activities, how we got into the building of welding machines. Our company has been in existence since 1956 and was originally engaged in the mining and exploitation of tin ore, as well as the preparation of construction materials. For more than 20 years our group has specialized in the application of plastics in the construction sector.

In the course of the execution of major projects in the tunnel, landfill and building sectors, our technicians developed the necessary welding machines for our own use -- machines which hadn't been available on the market up to that time. The machines were built and improved on the basis of empirically gained experience and in view of their respective use. As our company has worked through the whole range of plastic membranes for linings on flat roofs to multilayer linings against pressure water, a whole range of welding machines has been developed, enabling us to weld membranes of thicknesses from 0.1 mm (4 mil) up to 4.5 mm (175 mil) on the job site.

Now let us take a closer look at our welding machines. Our first machine is called Monotrans, Monotrans because it is driven by one motor. It is especially for welding of membranes for vapor barriers, vegetable beds, and the welding of protective and packaging membranes to a maximum thickness of 0.5 mm (20 mil). The welding temperature is adjustable, and the forward speed ranges from about 50 to 100 cm (20 to 39 in) per minute.

Another machine is called a Duotrans 1. Contrary to the Monotrans, it is driven by two motors, synchronized motors, because additional power is needed for the thicker membranes and for different applications.

The double wedge is fed by two heating elements of 250 watts each. The Duotrans 1 can be used for welding PVC and ECP, tunnel lining membranes, pond liners, and swimming pool membranes with a maximum thickness of 2.5 mm (100 mil). It is possible to weld LDP membranes with a maximum thickness of 1.5 mm (58 mil) with this machine. After a special adjustment, PVC membranes with a thickness up to 3 mm (117 mil) can be welded.

This machine is equipped with continuous temperature control and continuous control of welding speed, and it weighs approximately 12 lbs (5.5 kg) out the transformer. The welding speed ranges between 70 and 160 cm (28 and 65 in) per minute.

As the specifications for testing are continually becoming stricter, we did not have a basis in 1990 to fit the welding machines with electronic control and logger units.

With the Duotrans 3, we can weld PVC, low density polyethylene (LDP), HDP, ECP and CPM membranes to a maximum thickness of 4.5 mm (175 mil). The double wedge is fed with two heating elements of 800 watts each. The Duotrans 3 is equipped with a permanent digital display of the following welding parameters: speed of forwarding feed; the time that the seam is going to be welded; temperature of the wedge; and the pressure of force.

The temperature of the heating wedge and the speed of forward feed can be changed with the continuous controls, even during operation. The pressure of the rollers can be adjusted by means of spring rods before commencement of work.

The machine can also be fitted with a data logger instead of the data display. Except for the pressure of the rollers, all previously mentioned welding parameters are recorded on the data logger. It makes it very easy for the technician to get the data. All he has to do is plus and minus temperature, seam number, and confirm it with an OK. It's all there for the technician to set the machine. If the seam number and the name of the seam welder are not stored, the machine won't start and you can't weld.

The key for the machine is only given to the project manager or QC manager, and he is only person able to play the data into a computer. There is no technician allowed to manipulate anything. Without the key it is impossible to do it.

If required, the pressure of the rollers can also be recorded on our modified model Duotrans 4, which is constructed with a stronger frame. It can be equipped with a chain, to pull it uphill if you are welding on a side slope.

A record is kept of all consecutive numbers of job sites, welding seams and interruptions. Times of interruptions are displayed. The Duotrans 3 can also be used for all kinds of lining geomembranes of medium to great thicknesses, For instance, tunnel inverts, open-cut structures, landfills, and engineering structures.

The following machine, the Monotrans Roof, was designed for welding roof membranes, waterstops, fabrication of the T-pieces, and landfill caps with double wedge seams that can be tested with compressed air. Continuous temperature control, continuous control of welding speed, permanent digital display, and adjustable rate of the pressure rollers, are standard features. It can also be equipped with a data logger instead of a data display. The data logger can be detached from the welding machine, thus making it unnecessary to carry along printing equipment that, in addition, needs to be supplied with power. Recorded data can be processed in the office on IBM-compatible PCs or adequate laptops.

All of our machines are equipped with 30 volts, up to a maximum of 45 volts, electric security potential for the safety of the work forces. Practically all our machines, especially these used in the containment industry, are equipped with voltage stabilizers. Even if there are major fluctuations of current, the seam will still have the maximum strength.

Thank you.

Clark Gunnes – Resicon

I just want to start out with a real quick story. When I was in college, I was on the rowing team and one day my coach asked me if I would row a single in a race -- a single scull. I agreed and I was cruising down the Charles River. We took off, and I don't know if you know anything about rowing, but after about the first five strokes in rowing, you go anaerobic. About six minutes go by, you're rowing, and you can't breathe. So your mind shuts off. We line up; the guy says go: I go.

How you keep the scull aligned when you're rowing in a single, you're lining up two posts. You're racing down the course and you keep those posts in line. That way you know you're going straight. So I put my head down and I just went for it. I looked up, my posts were in line, I thought. I'm tearing down the course, I'm getting farther and farther away from everybody, and I'm doing great. This is going to be my day. Beautiful spring day in Cambridge. I get down the course and my coach is waving his megaphone. In the boat, you can hear the people on the bridge -- we're coming to a bridge -- the Mass Ave Bridge in Cambridge. I hear these people screaming and everything is going on. I'm saying this is great; they are screaming just for me.

Just about that time the boat stopped dead. These sculls are long, little, skinny things. My coach had loaned me his scull that he used in the '64 Olympics in Japan. I broke the nose right off it -- crushed the thing. And as I'm sinking, one of the guys from the bridge yells down "We tried to tell you." I had hit the abutment on the bridge. I guess what happened when I started stroking was I put my head down and I shifted over one lane so that I was lining up one of my posts with someone else's post, and I was going across the course. Well, I learned a lesson from this. The first thing is sometimes when you're working real, real hard, all you are doing is sitting on it and going backwards. The second thing is that it's a real good idea to listen to someone who's looking ahead if you're sitting on your butt and going backwards, because they may be able to tell you something. And the third thing is that the thing which stops you the most is usually that thing which has nothing to do with what you are doing.

These little lessons I try to incorporate into my worries about smart welders. The gentleman from J.P. Stevens was talking about smart welders. He's right. D.C. Taylor developed smart welders back in the early eighties I think, which were roof welders. The smart roof welders can work well, but if the technicians are no good, or other problems happen, you have a problem with these welders. I worry that we are going to overtechnicalize this thing, that we are going to collect too much data, that we are going to try to make the welders too smart.

One of the things with the data acquisition welders and the quality of the seams or the quality of the installation, is that we should look at a goal. What is the goal of this whole exercise? The goal is to make tighter installations, to make better installations, to make them longer lasting. You go out and you put in a liner system, and then you test it, and if it leaks, you go out and find the leaks, you fix the leaks, and then it goes into service. I have watched the data acquisition welders over in Europe, seen them in Austria and in Germany, in Czechoslovakia, and in Italy. What I have found is the same problems we have over here. That is basically, first off with wedge welding, if you have a good technician and the welder is tested before the seam is made, with some sort of test, that you get a reasonably good seam. And that's not to say that we shouldn't be acquiring data. But I'll get into that in a minute.

The problems that I've found with wedge welding are contamination problems in the seam and moisture problems. Those are the two areas. With textured sheet there have been some problems with the blowing agent in the texture sometimes. These are problems outside of the welder though.

The biggest problems I find are with extrusion seams. Where we have found most of the leaks in our experience in doing QA and in doing forensic work is with the extrusion seams. At cross seams where you make T-welds, at patches, and at transitions. There's no real good indication of poor seaming for extrusion welds. How can you make a good extrusion weld? You can set up your machine and everything else, but can never guarantee we get good extrusion welds. The failures that we find also in these areas are failures within the substrate.

Penetrations, appurtenances, and expansion -- when we are trying to make a tighter installation, if that's the goal of this whole exercise, then we have to look at those items. Therefore, the bells and whistles, as I would call them, or the extra things that we can put on wedge welders, can become more complicated, but may not be in the best interest of the process -- may not give us better installations.

My feeling is that ultimately here in the United States, and in all of North America, we will end up with data acquisition machines. I think that's going to happen. That's the natural trend, to try to get more data, even though I feel that the returns for wedge welding, in terms of getting good welds, are diminishing because the current wedge welders are very good. Everybody who has developed a wedge welder has had problems with them initially. I have watched wedge welders get better and better and better for everybody: Gundle, National Seal, ourselves -- you name it -- everybody that has wedge welders. And I think that one of the things that I would agree with Fred Struve, if you can make a mechanically better welder, you're going to have a better welding seam.

If we are going to make data acquisition machines, and we are working on one, it's no different than any other ones in terms of what we want to accomplish, or how we want to accomplish it. We may use different components, but basically all are quite similar.

What do the machines really need to have? First, the data acquisition part of the machine needs to be retrofittable to the wedge welders out there in the field now. I think that Bill Walling's comment about the cost of these things -- is right. You're talking about $2,500 or $3,000, up to $10,000 per unit, depending on what you put on this thing. That's a lot of money, especially since there are a lot of installers out there now who make their living from this.

They should be retrofittable. They should be made as inexpensive as possible. The parameters, as far as I'm concerned, should be the seam number, the machine number, the operator designation, and the seam length in terms of the machine saying we did this much seam without stopping. If the machine stops in the middle of a seam, you know the machine stopped in the middle of the seam.

You need standard speed, temperature, and pressure. I feel those are important variables, and I think those things need to be graphed. I think if they are printed out they are going to be of no use to anybody in terms of just rows and rows of numbers. I think these things have to be graphed so that you see them, so that you can see what's happening. I also think that this stuff needs to be in real time, or as close to real time as you can get it for the job site.

One of the things that we do is try to function in real time as much as possible for the sake of the installer. When the installer gets out on the job site and something is wrong with his equipment, what if he runs? What if he has a great day in production and all the seams are lousy? It happens. Everybody has gone through that agony, and quite frankly, as a person who runs a QA firm and also has some people doing installing, I can tell you I feel like a fool because we didn't help catch that.

The only other thing which nobody mentioned is that really what these machines need, as well as all these other parameter and data-gathering things, is a large spring-loaded device. It can be a 2x4; it can be whatever, that hits the technician on the head when the machine gets out of kilter and he isn't watching. It's got to be about six feet long so it can get all the way to the back of the machine and get him.

The other thing that the machines need is adjustable nip rollers and adjustable wedges. That's to account for variations in the seam and variations in pressure, so the machine can be adjusted to the site. When we see thick materials and thin materials, you find that your balance between one roller and the other changes, even one side of the roller with respect to the other.

That's as much as I'm going to say about the machines themselves. I think that data acquisition is important. As I said, we don't want to overtechnicalize it. I think that would be a big mistake. We've done very well in this industry keeping it simple. The failures I've seen have been failures where people don't account for expansion; they don't account for types of penetrations that may come in. When you see a penetration at the very smack bottom of a slope, running into soil outside of that slope, you know very well it's going to leak unless you do something about it. People don't do enough about that in the review process.

How to make real changes in the quality of seams -- well I'm just going to run down a list, and I'm sure people can add to this list:

- Make the specifications realistic. I've been through a lot of agony with the major manufacturers, where we're the third party on a project where the specifications, not written by us, were unrealistic. Even though we tell the owner this is unrealistic, they still maintain the specifications. Some people think that harder specifications and higher requirements make a better job; they don't. Specifications need to be realistic so that you don't have to patch and cut and fool around with this thing, so that you don't waste the installer's time and the owner's money.

- The second thing is, and most people do this, is take test specimens off each end of a seam, the start and the end, and test those. If those test out, there's a chance that the seam in the middle is going to be pretty good too.

- The third thing is what to eliminate. Eliminate wrinkles with polyethylene. How are you going to do that? That's magic; you can't. Eliminate cross-seams. Again, you can't do that. Eliminate tie-ins. One of the places where we found big problems is tie-ins between old and new material. Eliminate penetrations wherever possible.

- Account for expansion. This is something which we're constantly working with the installers on, when we're on the project, trying to help them account for expansion, especially in very small transitional areas.

- Finally, good technicians -- good personnel.

So, on the whole, if you can get a little more data for the project from a machine that will double-check the other things that you are doing, the other things that I mentioned today, you'll probably have a good system. You probably won't have too many problems with it. And you'll be able to back it up.

Thank you.

Bill Strachan -- Rumpke Waste Disposal Systems

I'm the Engineering Manager with Rumpke. First, just to speak to the owners' interests, I think the owner is interested in a quality job and a liner that doesn't leak. However that is achieved the owner doesn't really care. The other thing that the owner cares about a lot, as you know, is cost control. I think that there's maybe an inkling of some things in this workshop so far I've seen that would go toward cost control. What I see interesting from an engineer's standpoint as a specifying engineer for these jobs would be anything that achieves less of a need for destructive testing. I think that's obvious because then you end up having to make another seam or patch that's even harder to test.

Another thing that interests me in this area is variable testing frequency according to the quality of the performance of the job. I think that's a good idea and I think I can see how I could work something like that into a contract, which goes toward cost control. I think where EPA, GRI and the manufacturers could get together is on giving some better guidance on reasonable specifications. I have known of some jobs where they have failed due to unreasonable specifications, ending up costing the owner considerable money unnecessarily. Basically, I thought the approach of some of these engineers was a CYA approach that's just overly protective. It ends up, as was said before, in no better quality.

Something that goes along with that is to see the regulatory community become educated on these machines and to allow for flexibility in specifications and testing frequencies.

John Workman -- Laidlaw Waste Systems

I have just a couple of brief comments. I've always contended that we need to improve the quality of seams. Seams are probably the least reliable part of a landfill. In order to improve the quality of the liner system, thereby improving the reliability of the system, somehow we have to come up with a continuous method of monitoring the quality of the seams. You can take a sample at each end of the liner, and get good results. But it really doesn't tell you a whole lot about what's in between those samples. Or if you take samples every 500 feet, there's nothing to guarantee you that you don't have a problem with the seam in between. Therefore, I've always felt that somehow we have to get to a point where we are continuously monitoring the quality of that seam, so that we can be sure that we have a reliable one.

Now, as Mr. Strachan said, the cost element is important. Chuck Rivette of BFI gave a very good presentation at the GRI seminar last December, where he showed that the CQA costs associated with the installation of a liner system are greater than what it would cost to put in an entire redundant liner system. So there's an imbalance here.

If we move to a more automated type of welding system, which records the properties of the welder, maybe that is a move in the right direction. In fact, I believe it's a move in the right direction, not only to improve the quality of seams, but somehow reduce the number of manhours that go in from a CQA standpoint, and thereby reduce the cost without reducing the quality of the system.

Steve Pekera -- Hazardous Waste Engineering Section, Indiana - Department of Environmental Management

What I have seen so far, as far as automation goes, is that it seems to be going in the right direction. We would like to see something that can monitor the quality of the seams. However, being new, I think we have to look at the reliability of the machines, and still leave a lot to the judgment of the CQA personnel at this standpoint.

I kind of agree with those who have spoken and said that judgment still has to be part of it. You can't just rely on a black box. There's going to have to be something that you can calibrate these machines with to give you some indication at the beginning of the day, or at the beginning of the seam, that the calibration of these instruments is up, and that they are giving you reliable data or reliable feedback.

That's about all I can say right now.

Dan Campbell -- Solid Waste Division, Ohio EPA

Everything that's been said here today, we kind of agree with. The one thing that I would like to point out -- I agree with the gentleman from Resicon who talked about the technicians -- the State has to rely on the people doing the work. You are going to have to rely on the people doing the work. If you have a black box that's going to give you all this information, and you have an operator who's not going to pay any attention to it, it's not going to do you any good anyway. We do think, and I agree with the concept of having all this quality assurance in place, you need to have qualified operators. You've got to have technicians who are going to pay attention to the information that the black box is giving them on a day-to-day basis. Otherwise, none of this is going to be any good.

That's basically all we have to say about it. Thank you.

Bob Phaneuf – New York Department of Environmental Conservation

I basically agree with the other state regulatory agencies here today and probably as much with EPA, that what we are all trying to get out of this is better quality construction. In New York State, we have double liner systems. It's really belts and suspenders, a very conservative liner system. There's a lot of times when we'll look at a construction certification documentation and see a lot of problems with it. After you've got drainage material put on top of a landfill liner system, it's impossible to exhume it. Now you've got questionable data showing up in a certification report. As a regulator do you want to make them go back now because peel strength wasn't just where it should have been? Those types of details have to be addressed in the application.

Data acquisition welders seem like a very good tool for the project engineer who is writing a construction certification document, to maybe use, as was said earlier, as an indication of the quality of the rest of that seam between the 500-ft destructive tests that we're taking. It's going to be interesting to see how that project engineer is going to use that information to instill the fear of God into the installer and the people using the equipment, that we are looking for good seams. How are varying data going to be handled when you see a tickertape that says that something could be wrong, but our 500-ft tests are good? That's got to relate to some action being taken as to how that is going to be interpreted. I think part of that goes into bringing the CQA aspect of things into the engineering part of these applications. How is that engineer going to interpret that data, or maybe request that data from the installers?

Overall, I think data acquisition welders are good. Anything the industry can do, without making the costs go up tremendously, to tighten those seams will be an improvement.

Doug Wells – Serrot Inc.

I'm taking Bill Torres' place. He was going to talk a little bit about the smart welders. He has most of the information.

I think I'll just tell you a little bit about the viewpoint of the installers. As an installer with one of the best reputations in the country, not really the lowest cost, we have to emphasize value in our work. We emphasize qualifications and training. We do an awful lot of training with our welding technicians. We have a data base in which we keep track of the names of the welders, the welding machines, and what their pass/fail rate is. Some of our people have given this a fancy name; they call it the "Measure of Quality." We know what our weld rates are and what our individual technicians are doing, what their pass/fail rate is.

Each year we reward the 10 most productive welders, the ones that have welded the most welds with no failures. That reward is in money. There's no reward quite like cold hard cash.

We definitely see a big potential for these smart welders. We like the idea of process control and we like the idea that Clark Gunnes from Resicon came up with, where you have kind of a 2x4 and the little monitoring device comes along and hits the welder with it. We've had some experiences where the controller burnt out, and technician didn't realize it until he had probably half his seam done. So for that part we see considerable potential, and we also like the idea of being able to do a better job at the same or a little more or less cost.

So that's kind of our point of view on the subject.

__Bob Mackey – Post, Buckley, Schuh, and Jernigan__

I'm Bob Mackey with Post, Buckley, Schuh, and Jernigan. We're an engineering and CQA firm. My viewpoints are basically from that perspective.

As a CQA firm it is not our job to trust anybody, the installer or the liner material being placed. However, we have to try to build confidence with the people and know how to review liner installations. As an engineering firm, the last thing we want to do is start putting holes in liners. Why ruin a perfectly good weld? Why, especially with the wedge welder, which, I think everybody admits, is the best invention going right now, in comparison to the extruded welds do not seem to have the quality that we want. The wedge welders are fast; they are good; they are consistent. But the biggest problem with the wedge welds is that it is hard to tell a bad seam from a good seam by visually inspecting it. That's why we do random sampling, or once every 500 ft (152.5 m).

When it comes right down to the bottom line, we have to test. Anything that can decrease the number of tests means a better product for our client. It also means less cost to the installer in repairs. If we can decrease the number of tests, everybody is going to benefit. So how do we do this?

I hear that data acquisition is a possible method of recording how well we are doing. When it comes to CQA, we have to generate the data in real time. If we can generate that data to say that, in thousands of linear feet, at 663 ft (202 m), something went wrong but came back on line, then that gives us the ability to say that at 663 ft (202 m) we want to take a sample to check. That starts increasing that number from once every 500 ft (152 m) to one every 1,000 ft (305 m) or once every 1,500 ft (457 m). We have to build that confidence and we have to test.

I heard that, if the temperature variation occurring in the wedge has to increase, it takes 3 to 6 ft (0.9 to 1.8 m) for that increase to occur. Well, how long does it take for a leak to occur? We need to spot those locations down to the 1- to 3-ft (0.3 to 0.9 m) location on the seam.

The idea here on the wedge welder, if they are smart, is to reduce welder error. By reducing welder error, we reduce the number of samples needed. Training, I agree, is the best policy for wedge welding, or any kind of welding. If you have a good quality team, which large firms seem to have, and a poor quality team, you never know which one you're going to get at a particular site.

We have to be able to make the welding system less dependent on human error. But we also need to be able to give the information to the CQA firm and the engineering firm so they can check what's going on. Assume that wedge welder is progressing and that the CQA person is taking samples. If there's the window that you people say there is, if there's a temperature range or a speed range, why not generate that information for the CQA person so he has that information available as he's walking around checking how the progress is going. If he sees a dark cloud coming over and the wedge not slowing down or things are not heating up, he can point it out or know where to check, when that operator has failed to notice. Or he can see if the operator is still on line and know who he can trust.

I think it's good to know what the seaming windows are. The engineering and CQA firms are going to need to know that information. It hasn't been generated previously. Maybe we should start. The CQA person needs to be able to see when that technician gets tired or gets a little lazy. A 10-hour day out on a hot liner is difficult enough for anybody. In that way maybe we can increase the quality of the personnel out there, increase the quality of the CQA people, and reduce the number of tests, which I think is the key.

Thank you.

Randy Underwood -- CH₂M HILL

My perspective is not only as a consultant and someone who has had some QA experience, but also some previous experience in a past life of working for a company that was in the waste management business.

QA/QC is a very important activity. Some type of verification I believe is the key that people really look for. Generally the specifications, testing methods, and things like that are pretty well understood now and pretty well established, many of them by regulation and guidance. Where we run into problems is the verification, and hence, the certification of seams. I'm actually a geotechnical engineer and I know when we do compaction testing or something like that, we'll do one test for every so many cubic yards of fill or something like that, and basically say that lift now is good because x number of tests passed. It's representative samples in QA/QC. I feel it's the same type of thing with a liner when you do a destructive test at the beginning and end of the day, or whenever the QA person requires the person to run a destructive test. Those are indications toward verification, however, you're not actually testing every inch of seam except for the pressure test. We have to rely pretty much on something being representative.

The approach that I like to take is just the old-fashioned common-sense approach. There are certain indicators that you can look at. You look at the seam, as was mentioned, for certain types of welding that may be a little bit more difficult. You watch the procedure the welder is doing. You watch the seam. You do the tests that you feel are necessary. If possible, you try to do the destructive testing toward the end of the seam, so that you don't provide a problem in the liner.

All these kinds of things again come down to common sense. The advantage of the controls on the welding equipment and also the verification is just that. That's just one more tool and one more piece of information that may be very useful in saying that we've got better assurance or better verification between those points where we have the representative samples, or what we feel are representative. That has, of course, to be balanced against cost. Also it needs to be balanced against necessity, and I liked the approach this morning of having a QA task force. Sit down and take a look at whether what we're doing now is adequate, and, if not, what else do we need to do? There are a lot of extra things we can do that would be good, but, at some point it's probably adequate. Anything above that is good to have but it's not absolutely necessary.

I look at this as a real good potential for verification between points, as well as verification of seams. By the same token, if it's beyond what is absolutely necessary to do the job, then maybe the cost isn't worth it. That's something that would need to be looked at. That's just a feeling I've got. I really feel that it would be a wonderful tool also, especially in pond liners and things like that where, at some point, a problem should develop. At least it is some kind of historical record that you could go back and, instead of draining the pond and retesting, there might be some way of getting into areas where the problem may occur. I can see it being as a good historical record. Again, it costs money, and we need to take a look at the cost and benefit.

I would very well ditto the task force suggestion this morning, that we pursue something like this, but we pursue it only to the point of its necessity.

Thank you.

Ian Peggs — I-Corp International

It's great to hear of all this discussion on data acquisition welders and related activities. And it's interesting to hear the very wide diversity of opinions and approach as to what we're talking about. It's a lot wider than I ever thought it would be. I'm just wondering why that might be. I'm wondering if there's one reason that we're missing here.

I'm going to approach this from the materials point of view, not from the QA, not from welding, not from machinery, not from installation or anything else. I think we're missing one thing here and that is, what are the criteria for the success of good seams? We all say that we want good seams, but I don't think any of us know what a good seam is yet. I think if we're thinking of evaluating these seams, in HDPE for instance, then let's look at HDPE because it is one of the more intricate materials we are dealing with. I think we are nowhere near defining what a good seam is. If we think that peel and shear testing as we do it now defines a good seam, we are hiding our head in the sand. I think we've got an awful lot further to go.

We need to define these criteria. We've heard from Bill Walling (SLT) that he does his seaming and he's satisfied to have a 1 percent failure rate. One percent of what? I don't say that Bill did this, but if his criteria are just speed, temperature, and pressure, then it's very, very easy to get one percent. As your criteria improve and increase, it gets a little bit more difficult. You need to define what those criteria are, so that we all understand them, so what's a criterion to Bob Landreth (EPA) as a regulator, and to Bob Koerner (GRI) as a researcher, and other people around here, Mark as a manufacturer/installer, we're all after the same thing. I don't think right now we're focusing on the same thing at all. The thing that we're evaluating these materials on, the kind of test that we're doing, I wouldn't say they are inappropriate. They are good, as good as we've got so far, but they sure as hell need a lot of improvement. Furthermore, many of us don't use the information that's available from these tests right now.

The ultimate criterion has to be seam performance. We have to know what a good seam is, and then maybe we won't have as diverse an opinion as to what it is we're up to. If we know what we are after, we can all zero in on the same thing.

The conventional peel test that we do doesn't tell us anything about the seam, other than exactly for the sample where we do the peel test at the edge and at the edge being stressed.

Assume a good seam failed the peel test at the edge of the seam. One side is thicker than the other side, so it didn't peel right down the interface. It peeled down the edge of the heat-affected zone, but it peeled apart at a very high strength, basically the strength of the material itself. Is that good? Is that bad?

In a number of specimens where we had 100 percent separation we still had very good strengths. If we were looking at HDPE in this case, we would say that the HDPE was no good because it peeled apart. What do we do? What is it that is happening here that we don't understand, but we need to evaluate? Are such occurrences actually good seams or not?

From what I've seen, when there's a lot of residual stress, crazes are initiated, and crazes can become stress cracks with time. We need to understand those kinds of things. Just where is this window? And what gives us an acceptable situation?

In may QA work, I require that there be no seam separation or a minimum amount of seam separation on a peel test because of the possibility of inducing crazes. If you can cause a seam separation, a peel separation in a lab, as the liner in the field is stretching back and forth and rippling and waving, it's quite easy to see that, over a long period of time, you could have some seam separation there, induce the same kind of crazes, and reduce the stress-cracking resistance of the material. Tests that we did on this kind of material in the lab show that those crazes can reduce the stress-cracking resistance by about 70 percent.

It is important that we know the seam characteristics as to what is giving us a good seam, what is giving a long life. What happens when we make an extruded fillet seam, what happens when we heat and apply this material? We melt the material. That's what we're trying to do. We're trying to melt it so that it will mix, so that the surfaces will bond together and resolidify, so that we have a new structure of material in here. This is a somewhat oriented material in the geomembrane itself. We melt it, we let it mix up, we obviously have a more homogeneous, a less oriented chunk of material. Right next to it, between what's melted and what is original material, we have a heat-affected zone where the heat associated with the melting has obviously influenced the structure. Maybe it has increased the crystallinity of it because of the annealing. Things happen around there. If we have an orientation gradient there, or transition at that point, is that something that induces stress-cracking?

I did some very preliminary investigation of the microstructure of the edge of a fillet extrusion weld where there was a stress crack. I took some very small samples out on either side of the crack into the seam and into the geomembrane and did some density gradient measurements. I found that there were indications certainly of changes in density at the edge of the seam, at that point. Certainly, it's not surprising that there would be changes in the material due to the application of heat. Same thing with crystallinity. There were some crystallinity changes from the seam into the geomembrane. Oxidative induction temperature -- same kind of thing. We just heated the material up to see at what temperature it would degrade and we got something different, a transition point in the area where the cracking was occurring.

One of the very interesting things I think was when we had to do some repairs on a seam that had stress-cracked or a seam that had stress-cracked partially. The cracks hadn't gone all the way through and the installer didn't want to put lots of extrudate over the top and he didn't want to cap-strip them, but just wanted to lay a bead over the top of them. I was very adamant that reseaming should not be done, so we were experimenting with different widths of beads to get it across the original stress crack so the edge of the bead was away from the original seam and wouldn't be affecting the geomembrane in that area too much. We did the notched constant tensile load test. For the original seam, we put the notch right at the edge of the seam.

We had a time to failure of somewhat just less than 200 hours. The original seam with a repair on it with an extruded bead on top of it, in this particular case lowered the stress-cracking resistance although the failure times were somewhere in the region of 120-130 hours, definitely a decrease from what we had previously. We then tried to repair this seam so that we could get back to where we were originally. We didn't want to make it any better than it was originally because there would still be some of the original seams about. But we wanted to at least get the repairs back to the standard of the original one. We did one repair procedure, tested it, and it was hopeless. We went back to the installer. I don't know what they did. They did their thing. They played around with things and they came back with another seam, and found that they had improved it somewhat, but it still was not good enough, to the condition it was previously. We went back, played around with it again, I don't know what we changed, but it looked the same. It came back, we did the test, and found that we had something very close to what it was before, so we felt comfortable with that. We went ahead and did the repair according to this kind of procedure rather than any of the other ones, so that we knew that we had reasonable material.

There are a lot of things that influence the performance of seams. I think the kind of data acquisition and process control that we are talking about right now very interesting. I think a lot of people are right that we don't want these kind of machines going into the field. I don't think they will be field-hardy. But that's not the intent. I think right now we're in a transition phase where we need the kind of information that these machines are going to produce in order to see what those changes do to the quality of the seam. Then when we understand what's happening to the quality of the seam and we know what kind of parameters we need to look at, then we can zero in on the kind of machine and controls that we need to do what it is that we want.

Thank you.

Jacques Cote -- Solmax

We are installers. As an installer, I'm going to give you truth. We are interested in getting in and out as fast as possible with a quality job. To do so, we use material, we use equipment, and we use skilled labor. The important thing when we are using material is to get material which is easy to weld. We need also, and it's not available on the market at this time, some protection products on the surface to be welded. I know it's possible to get that type of product right now in Europe. It could save a lot of time in cleaning and giving a better surface to be welded.

We want the equipment easy and simple to use. I don't want to hire an engineer to operate my equipment on site. It has to be reliable. If it breaks on every hour it's not good for our trade. It has to be easy to maintain. Again I don't want to hire a mechanical engineer to fix my machine on site.

Skilled labor training is very important. That's what we are taking care of at our place. QC people are very important also to have a quality job. We have to do our job and we have to be helpful in assisting the QA people on site.

We are certainly for process control and data acquisition. There is no doubt in our mind. Machinery developers should keep in mind that people using these things on site don't all have Bachelor's degrees or Master's degrees. I would like to point out that for equipment, it has to be easy and simple to use, reliable, and easy to maintain.

Thank you.

Peter Barbey -- SLT-Germany

I am Peter Barbey, Technical Manager of SLT-Germany, which is a sister company to SLT-North America. I will give some comments from the point of a German manufacturer and installer of liners.

I believe we have started the development of the data-recording system in Germany under pressure of our authorities. I think you are in a position that we were a few years ago in Germany and you are making the same mistakes that we made two years ago.

The question from your side was what is a good weld seam? I will give you a very simple answer. A good weld seam is a seam that has the same properties in 100 years as it had shortly after welding.

How do we get good weld seam results? You need long-term tests to define the stress-crack resistance. What we have at the moment in Europe, and also here in the U.S., are only short-term tests, like the peel test, the shear test, or sometimes a pressure test. With these tests, you can't determine the behavior of a good weld seam.

We have on the sites now very sophisticated wedge-welding equipment. What we need is very simple equipment. We have from the installers two groups of persons. The first are the ones who become very nervous when they have a wedge welder with a data recording system. They concentrate on the right programming. They look at whether the recording system is working, but they don't concentrate on the welding process itself. The other group is the following. They say OK, we have equipment and the data-recording system is a very perfect system. Nothing can happen. OK, let's make a weld seam and we'll see the copy. And they don't concentrate on the welding process.

We have to reduce technical requirements to the personal staff, so that a very simple-minded person on the site can weld with the system.

I think before we define our weld bubbles, we have first to define the right parameters or the right criteria to get good weld seams.

Thank you.

Dr. Rolf Preuschmann – Germany, Federal Institute of Material Testing

I am also from Germany, from the Federal Institute of Material Testing. Engineers, physicists, and chemists all have an interest in having a very good material and a very good system for the landfill so that in the future we have good water for our children. There are so many aspects. You know that the welding is a very small aspect. But we saw in the past nobody knows enough about welding. All of them proceed by experience, but not by science.

So we say give us your parameters. Nobody can give the parameters exactly. One says high temperature, low pressure, high speed, small speed, everything was done. We said please be so kind, document it, and they say it is impossible. Thousands of values we counted. In Germany the government has a strong role in prescribing conditions. We can say do it and they must. So we say please do it, but the please was not the interesting part of this.

In this way, all of the installers must have data acquisition wedge welders. They must monitor five parameters, including the pressure, the speed, the temperature, and to find out the point of failure. We had major effort to develop the data-recording welding machine. That is very expensive. Some million marks have gone to have a good system. The Pfaff competitor can relate a bad story of it.

Now all German landfills, with the approval of the BAM, must have data-recording welding machine and now we have the data. What shall we do with the data? There you are right. We must make interesting tests to say what is the long-term behavior of the welding. We had three or five years ago the research for it, but we had no good answers for our questions. We searched for new answers. We must do a lot of work to find out the long-term behavior of the seams resulting from various welding parameters to have a good experience and to say that's the right way to weld and to have good long-term stability for the landfill.

Thank you.

Frank Sinclair – Sinclair Equipment Co.

I'll be real brief. In my presentation, rushing through, I forgot one point I think might be of interest to some of you concerning the Pfaff welder. Pfaff has had the 8365 that I showed you this morning out in the field for 2 or 3 years. We have presently about 50 units in the field in Europe. So this is not a prototype that we are just playing with in- house. It is something that is being used daily in Europe.

On a lighter note in closing, I can guarantee you I've never run my boat into a bridge.

Steve Menoff -- Chambers Development Co.

Waiting until the end of a workshop is always bad. It gives you an opportunity to put notes together to write a speech which hopefully should have been briefer.

Somebody said that you could only have two of three things earlier on, and I think it was good, fast, and cheap. I think that is a pretty easy decision from my perspective. I would want good, and I wouldn't use the word cheap; I would say cost-effective. Fast has, unfortunately, never been a concern on too many construction jobs that I've been involved with, so I don't think we need to focus on it.

From the perspective of an owner/operator, the overall goal we're looking for is to reduce our liability. The specific goal we're talking about today is good seams. I think you need to realize there are a lot of other things that go into the making of good seams. There are waste restrictions, siting criteria -- where we put these facilities in the first place. The liner is certainly a critical component, but it is just one component of the overall program that EPA administers and the State regulatory agencies administer to protect the environment. In that context, my thought as I listened to many of the speakers, particularly this morning, was it's always good to generate data, and the more data we have, hopefully the better we'll get at what we're doing here. However, data for data's sake kind of scares me, because data for data's sake leads to more consultants to evaluate the data, more people doing QA work, and it's not the overall end result that I'd like to see.

What Fred Struve said I think is critical. If we can solve the problem of getting a better weld through a mechanical solution, that addresses all of these concerns, that self-adjusts itself, I think that's what we're all looking for. If the data lead us to a better welder, we're all interested in it. If we can do it without spending years of research, that's certainly an avenue I'd like to see pursued.

If these welders lead to increased confidence in the quality of the welds, I would hope we could get to the point where we could reduce the level of QA and, hopefully, the level of QA costs. Particularly, the area I'd like to see reduced is destructive testing. It's something, as Gary Kolbasuk (NSC) said, that's inherently contradictory, putting in liners to protect the ground water, and then cutting holes to make sure that they are OK. We're coming back in and using a welding technique that, I believe Clark Gunnes (Resicon) said, is the only one we've had problems with. We've really made a lot of progress with the wedge welders. I think there is good level of confidence in it. And yet we come in and, in order to restore our confidence, we cut holes and use a welding technique for which we don't have a lot of good methods to check non-destructively and we don't have a lot of confidence in.

I'd like to keep that in the back of our mind, that we shouldn't just be generating data. It should lead to something definitive that has some sort of a cost-benefit payoff to the owner/operator and ultimately to the public.

There has been a comment about improving the level of the technicians. I agree with what Jacques Cote said -- we don't want mechanical engineers out there, because that leads to the other problems that I've addressed. But I don't know if we shouldn't try to improve the level of craftsman who is putting in these liners. We have a lot of very good people out there, and I think we need to keep that in perspective. The Industry has come a long way in the last five years, certainly in the last decade. There are programs in place, and EPA, GRI, and other groups are pushing a certification program for the QA people. Maybe a better place to start would be a certification program for the installing technicians. Again, do we focus on better checkers or better craftsman? Maybe the focus should be on doing a better job in the first place, raising our level of confidence in the product and reducing the level of checking that comes after the fact.

Those are the only comments I'd like to make. Thank you.

Bob Koerner – GRI (Geosynthetic Research Institute)

I'm very surprised at this point. Of course, we all have preconceived notions of what a workshop like this will be or not be. I'd like to put my own two comments in before I try to summarize.

We've heard a lot, even right to the end here with Steve Menoff (Chambers Development), about quality of the technicians doing the work. Yes, it's critically important. It's not a question of do you need good quality technicians. It's how do you get them to do good quality? I submit to you that of all the emotions, even giving them money for prizes, and I applaud the Serrot approach -- I've seen their data, it's marvelous, but the real emotion to get someone to do something good is what? How do you get people to give you attention? How do you get people interested? It's what a professor does to students. You invoke fear!

Don't laugh. I am so serious. As a young man, I used to think that respect and knowledge and all these other terms were what gets attention and quality. It's not. It's fear. I can tell from teaching courses. I teach courses all over, as a lot of you know. When the people are coming in because their boss sent them or something, they're not really serious. However, if I had to give every one a test at the end of the day, they'd be glued to the seat. Fear is the motivation.

I submit to you that data acquisition brings fear into the topic of good seams. One learns results immediately, not two days later, or two months later. Listen to what Bob Phaneuf said, when the data comes to Albany, the facility is covered. There's solid waste going in at that point. Is he going to reject the seam then? Look at the position we put a Bob Phaneuf in after the facility is built and finished. Even by the time the data gets to your office, Steve Hanoff, the liner is installed. You really can't make a decision. The decision is made in the field for you owners and regulators who really have the ultimate long-term liability. We need the decision right now, Bill Walling -- immediately -- while the seam is being made out on the field. This is the flaw with the current status. It's not quick enough. At best, it's two Federal Expresses back and forth to the quality assurance lab until they do the tests. We need information right away. We need real time. That's the key word I think I'd like to get to you and I think that's what these machines bring to the technology of seaming.

The second point of my personal comments that I'd like to mention has to do with what Ian Peggs brought out and our two colleagues from Germany said as far as how you assess these seams. The state of the art all over is shear and peel tests, of which the peel test is probably the better of the two. The formal adoption of a peel test as we have it in the United States is still floundering somewhere in ASTM. Peel elongation is still only looked at by very few people. There is a QA manual that a lot of you know that Dave Carson is the EPA Project Officer on. We were just afraid to death to talk about peel separation. We just didn't know how to approach it. There was so much controversy, we left it out, but it's a critical issue.

As the people who spoke to the issue mentioned, peel, shear, and air testing are short-term tests. With a bit of trepidation, I submit to you we might have a long-term test available. It is not a simple, nor index, test. It's a variation of the notched, constant-tension, load test which is now an ASTM test. That is a very long-term test. There are two variations of it, a single-point test for the sheet and a seam test. I submit to you that the seam constant-load tension test might very well be the long-term approval test to see what a good seam can do over the long term. It's using that test that the long-term welding window or welding bubble can best be established by. But this is not a trivial task to do. Of course, it takes a lot of time to get this data, but perhaps we should start along that road.

SUMMARY OF WORKSHOP BY BOB KOERNER

Let me try to summarize the presentations thus far and then we can have questions and answers. The way we set up this workshop was to have the people who are actually doing this work present their feelings. It's obvious I think to all of you that National Seal, from Gary Kolbasuk's point view and Gundle, from Fred Struve's point of view, are very much in favor of this technology moving forward.

On the other hand, it's very obvious to all of us, and excuse me for being very open, that SLT and Poly Flex have less of a comfortable feeling, even to the point where they object to bringing it out. So there's definitely a diversity of opinion, even within the polyethylene community.

If we move over into the more flexible materials, like PVC, we heard from Fred Rohe. Fred seems very positive on it, but that's just one person from this entire community. I would sense that there's less of a positive feeling than Fred has, and he's probably leading the group in that respect. But that's an assumption.

We heard from Glenn Zenor of JPS, who brings us experience from the roofing industry, and Glen goes back to good craftsmanship. It's interesting to learn from the roofing industry that it has approximately 200 courses a year on how to install roofing membranes. The Roofing Institute people have the experienced installers doing the work come to training, and they give installers certificates upon passing the week-long course. If you really want to go in this direction and you really want to get serious about high-quality installers, other than from a company-by-company perspective, certainly we can learn something from the roofing industry.

We heard from the manufacturers of the equipment, Pfaff, Bauveg, and Resicon. I was a little surprised at Clark Gunnes' comments. I didn't think has was as supportive as the other two speakers. I think all three manufacturers are to the point where they can give us pieces of equipment that can measure this data, with the possible exception of the sheet temperature. Look carefully over Gary Kolbasuk's paper in the Geotechnical Fabrics Report, and you'll get more detail of how he is measuring the actual temperature. It seems Fred Struve is interested in that as well. That seems to be a parameter which is not standard on the equipment that's available currently, and it could be the next upgrade in them.

We heard from the private owner/operators, Rumpke, Laidlaw, Chambers, and certainly they are all interested in quality. They clearly have to be. It was interesting that none of them said the cheapest cost and quality. They said good cost-efficiency or words like that. Certainly cost is a factor, but it's not the dominant item. The dominant item is the best possible seams that we can get, and that was very encouraging.

It's good to see that the State regulators are here, Ohio, Indiana, New York. We certainly appreciate you people being here, just as far as knowing what's going on and staying informed. We think that's great.

Perhaps the consultants doing the QA work were the most positive group in looking at this data. I don't think the installers and manufacturers really appreciate the point of view of the consultants. Sure, there are good consultants and there are poor consultants in everything. They're not going to use the information from data acquisition as a weapon. They want to know what's going on as much as you do. I would be surprised if you saw in a specification where they are setting your basic three parameters. I don't think a consultant is so naive as to do that. They're interested in their part of the operation. As far as using such data, go to soils QA in the compaction of clay liners. You don't see specifications where the water content has to be a certain value and the density has to be a certain value. No consultant is going to use data in that way. At least, I don't think they are. I don't think that's a realistic fear, if that is your inherent fear against using these machines.

Ian Peggs brings us the long-term thinking, and I think that was marvelous of what really is the long-term objectives. Jacques Cote is certainly interested. Jacques brings one other thing, and that's clean seams. I don't know if he went over this item too quickly. In Germany, there's a 4-inch (10 cm) film strip that must advance in front of the area to be bonded. Some of our problems are certainly dirt in the seams, as well as moisture in the seams. We see towels being pushed in front of these welders, all kinds of paper napkins, and everything like that. Are we ready for a film strip? As Dr. Preuschmann mentions, the German EPA can order it. Can our EPA order these things? Maybe not. At any rate, this is very intriguing. It's interesting when the American manufacturers who go the German market have to do that. Why not here? Well, somebody has to push them. Certainly the dirt and the moisture can be nicely avoided. Then maybe the three parameters rise up a little more as being more important than what they are now.

Essentially I think with data acquisition wedge welders we have an interesting tool. We have great divergence of opinion, but that's what these workshops I think are all about.

COMMENTS, QUESTIONS, AND ANSWERS

Comment from Glen Zenor of J.P. Stevens -- What I wanted to mention with Ian Peggs is that we did this work, not as extensive as you did, but in our heat-welding experience, and this has nothing to do with wedge welding, but with hotter welding, the temperature wasn't nearly as important as the BTU's of the output of the nozzle, and where you measured that. We did a lot of work where you have a voltage drop. Your temperature may remain the same, but your BTU's would be dropping. We saw a big difference in welding in our particular field and wondered if you had done any work on that just to corroborate what we've done.

Response by Ian Peggs -- He's right.

Comment/question from Steve Pekera -- For Ian Peggs again, I'm also kind of curious as to the heat-affected zones that you've looked at in the welds. It brings back some memories from my past employments and things of metallurgical welding in wellheads. Where they had the heat-affected zone, they had a lot of embrittlement problems. They found they had to do a lot of post-heating to control the temperature after the weld, to bring the temperature down at a slow rate, to prevent that material from being embrittled. I was just wondering if any of that has been looked at.

Response by Ian Peggs -- I don't know if we've really looked at that. I think that's the kind of thing we need to do. A long time ago, and I can hardly remember, I was originally trained as a metallurgist. That's why I come into the geomembrane field with the kind of comments that you're talking about. I spent a lot of time in the oil industry and I got into plastics from previously. I'm just using the technology and the information that I got previously. I think it's that kind of thing that we need to apply to these seams as well. Certainly, annealing can be a problem. Obviously, cooling rate is a very important thing. We know that when the wind blows, we get different kinds of things. Temperature is one thing. Heat input is certainly the main thing, rather than temperature. We need the required amount of heat to reheat the required amount of material to the right temperature. Then cooling rate is very important.

Comment by Steve Molnar -- I'm from the Edison Welding Institute in Columbus, Ohio. Let me just emphasize what he just said. We have looked at the effect of weld morphology on bond strength and I'm doing that right now as a matter of fact. If you are preparing the weld correctly, in many instances, the morphology will not affect the bond strength. We always look for failure in the bulk material. There's no question that morphology does indeed have an effect on bond strength and on failure mechanisms; but unfortunately, in polymers, right now, we're lagging the metallurgists by quite a few years. We've developed some very nice photomicrographs in polarized light that make you convinced that it has to have an effect. We are looking at it.

Comment by Gary Kobasuk -- One of my concerns for a long time has been that we never know why welds fail when they do, and then when we do look at welds that we think are good, we look at microtomes and we see all kinds of funny things, and we don't know what they mean. We are doing work on it and Ian Peggs has mentioned a little bit that Rick Thomas is working on. We are trying to find out, through accelerated testing, long term testing, what the effects of these different things that we see are. For those interested in pursuing it, we learned something from our friends in Germany that Igepol® is the wrong thing to use. Igepol® has a cloud point of about 52°C (11°F)so it comes out of solution. To accelerate the testing, we need to go to higher temperatures like 80°C (27°F) that and it stays in solution. We're beginning to get some very interesting results. They're all preliminary right now, but we are finding some correlation between what you see in the microtomes and the long-term performance.

Question from Bob Mackey -- One thing that concerns me, and I want to mention it to all the manufacturers, is the idea of voltage drop. We have the equipment that's going to give us some good information and maybe utilize this information, but it's not going to be able to tell us the truth if we're not supplying adequate or consistent power. You get voltage drop or a voltage surge. The machine is trying to put out all it can, but it doesn't have the power supply to do the work. Are you, in some way, trying to correct this problem in your welders? We all see the kind of generators that are out on the site. They're little things that you pick up at the hardware store. These are not what I call quality-rated pieces of equipment.

Response by Fred Struve -- I did briefly allude to that earlier. The computer-driven controllers like the speed controller and the temperature controller can cope with a pretty wide swing of voltage, provided you have an adequate wattage in your heating element. As the voltage drops, it will just increase the on time, and it will compensate for that. But there is a lower threshold where the thing is already on 100 percent of the time. When your voltage drops below that point, you're lost and the temperature is going to drop. So these electronic controls, that's what they are there for. They're there to compensate. As your line voltage drops, the speed drops on your DC motor. The sensor will pick that up. It will increase the voltage that it feeds out again in relation to the input voltage. Currently, we put on all of our machines a voltmeter that a man can read while the machine is operating. That's one of the problems that we have with technicians. They'll put a voltmeter into the leads with nothing working and say oh, that's beautiful; we've got 120 volts. But they've a tiny 3-mile long extension cord, and the moment you take a microamp out of there, the voltage drops 10 volts. They really have a problem understanding that you need to measure the voltage when the machine is operating. So we actually have built a voltmeter into all the machines now that works continually while the machine is running. You see that thing fluctuate. As the heat is switched on, it will drop from 122 to 116 or something like that, and then go back again. That's not a problem. All those computer controllers are made to actually compensate for that. The only problem is if it drops too low, and in our case if you let the voltage drop too low, to about 112, then you are running the risk of the temperature not being able to keep up because you've dropped the power in your heating elements so much, that even when they're 100 percent on and you are welding at 8 feet per minute, it cannot maintain its temperature.

Question: Do you think that data acquisition could record that also?

Response by Fred Struve: It does. One of our channels will be voltage. In any case, you don't really have to fear it, because, if you're monitoring your wedge temperature, that's your direct indicator. So the voltage is really a curiosity, because then if you do see a problem with your wedge temperature, say, at 180 ft along the seam, you see something funny happened, you have the voltage graph as well, so you can see whether it was related to that or not. As a diagnostic, it's good to record the voltage channel as well. But essentially it's not necessary.

Question: -- To anyone who can answer this question. Considering Subtitle D, we are going to see in the future larger landfill units. It is cost-effective to install the whole unit at once. Many of the facilities don't fill up that unit for two years. What is the effect when you leave that synthetic liner exposed for two years to temperature changes? We saw in the chart, the temperature could rise up to 150°F, and in the winter it could drop. What's the effect? We get the certification report immediately after construction. As Ohio EPA, we certify those cells every time they install those liners. We get the report and everything is acceptable immediately after they install those units. Two years down the road, there's no one going to do any testing, especially on those seams. What's going to be the effect of the temperatures during this exposure on those seams?

Response by Gary Kolbasuk: We do a lot of long-term aging studies of the materials we make as I'm sure the other manufacturers do, particularly oven aging and UV aging. We currently have seams out in Arizona that have been exposed for over a year under no stress, constant stress, and cyclic stress. We are also doing oven aging, and the encouraging news is that accelerated aging is not showing any real change after the equivalent of about five years. We don't have the really long-term data yet, but I guess I'll just say at this point that it's looking encouraging. We're generating it, and hopefully in another year or two we'll have enough to either get real worried or to put everybody's mind at ease. Earlier at GRI we decided there were six important parameters. I only talked about five. That was for good reason. The incoming line voltage is critical. Therefore, it was our sixth parameter. The graphs we get from the field showing it at 122, say, until the heaters kick in, and it drops to 108, and the heaters go off, and it goes to 122, and to 108. All of our electronics, the controls, the computer, and everything, are all run on 12-volt DC. And they have a battery in there as well, so that it doesn't affect those. What it does affect is motor speed. You might have noticed from my graph on the motor speed, where you expect to see it flat, there are little peaks going up and down, even though it was only one or two tenths of a foot per minute. Those happen to correlate directly with the heaters going on and off.

Comment from Clark Gunnes: I just want to revisit the question about the cells that are left open. It's not just in landfills. In New England it's been our experience that the material does not degrade. It's that certain welds open up a little bit. Usually these are extrusion welds. I'll tell you, it's very difficult in a landfill or any kind of structure. We were brought in to advise a contractor who did some work for one of the power companies in New England. What was happening in these lagoons was they had a certain minimum leakage that they had to meet. It was tremendously low, a couple gallons per acre per day. There was no clay underneath. There was just a geonet underneath the geomembrane. They'd fix it. It would pass. Two or three months later, it wouldn't pass. First, we got the authorities to raise the leakage up to 20 gallons per acre per day. They wouldn't go any higher. I wanted them to go even higher, because there wasn't just one foot of head on this liner, there was nine feet. I wanted it up around 100 gallons or 150 gallons. But we got them up to 20. They just have not been able to maintain it. What's happening is the liner is moving, especially with polyethylene. Some of the extrusion welds just keep popping, just a little bit, but enough to make the leakage happen. We see this in landfills, around areas where maybe the berm will meet the side slope. Thus you have the possibility for more movement or more bridging. We try to get people to isolate these areas so that they don't move so much, so the thermal expansion and contraction doesn't move these welds around. Again, most of these that we find are not in the wedge welds. They are in the extrusion welds.

Comment and Question: Just a couple of things. One would have to do with the exposure of the geomembrane. One of the things I'd probably be more concerned about is the clay liner underneath the geomembrane being exposed to freeze-thaw. That would probably be more of a problem, I would think.

The other thing is -- maybe I didn't catch this because I came in a little late this morning -- but the types of machines we're talking about, are they automatically compensating, as far as readjusting themselves to environmental conditions, or are they just more of a readout with the technician adjusting it as he goes along?

Response by Gary Kolbasuk: Both. You've got your choice. The basic part of data acquisition is acquiring the data, and from there you have choices of looking at it and making decisions on your own, setting limits where alarms go off to tell somebody to do something, or putting in automation, to make automatic changes as conditions change. And we're still looking at them.

Comment by Mark Calwallader: Guess I won't feel so bad about making a plug for a product of ours, since other people have shown off their products here. In response to what Clark Gunnes raised, as far as the tension that develops around the toe of slopes where you can possibly get the extrusion welds to pop open because of the expansion and contraction that takes place in the liner during the installation. There are products now available, including the white surface sheets to reduce this expansion-contraction problem and maintain stable temperatures, etc., and therefore a nice flat lay at the toe.

Comment from Ian Peggs: I'd like to dispel something that I see developing here, and that's about extrusion welds. Certainly, I think the evidence shows that extruded seams are not quite as good, in terms of their durability, as hot-wedge fusion seams. But I don't think we should be expecting them to pop open at any time, and accept the fact that that happens. Extrusion seams can be made perfectly well, and there's absolutely no excuse for them popping open unless they are badly made. As far as leaving the liner open or the landfill cell open, I think in practical terms, on the assumption that all the CQA and the installation have been properly done, and you got all the information that you need, the quality assurance information, the quality control on the seams, etc., really all you need to be doing is to make sure that at the coldest time when they're open, they don't pull tight. And if they do pull tight, if they trampoline in corners and put long-term stresses or cyclic stresses on the seams in any area, then you need to look at the seams, and make sure there are no little hairline cracks along the edges of the seams. If there is any tension developing, cut it out, put some compensation in, make sure that it works, and there should be no problem.

Comment from Bob Koerner: On the idea of leaving geomembranes exposed, if in a landfill you are going to cover it anyway, I think most of us would recommend to put the leachate collection soil on top of it. By having a facility exposed that long, you have not only the degradation concern, but vandalism and accidents, etc. So to leave a big cell, like you were describing in your remarks, open for a couple years, I think you really want to question that. As Clark Gunnes brought out, if you have a surface impoundment and you have seepage or seismic forces, then it gets much more difficult to hold the cover soil on. But in a landfill I would question why you would want to leave the geomembrane exposed for so many years. All kind of things are possible if it's exposed.

Comment by Bob Mackey: Down in Florida, it's cheaper to build a large landfill. You may not be able to put waste into several of those cells for several years down the line. What the regulators are going to start looking at is going back and recertifying that cell to make sure that any exposed liner is not damaged. It doesn't take a regulator to do that or a regulation. It just takes common sense. Anybody who has a landfill ought to be doing that in the first place.

Closing Statement by Bob Landreth: Thank you all for coming. On behalf of us here at EPA and GRI, we would like to thank the presenters today. I think you presented us with some information that will lead us to a decision point, which is what's going to happen now? We have taped this day's activities and taken notes. That's why we had the microphone passed around. We will try to produce a report within four weeks. It will take me about that long to get it out, so you should have it very soon. As soon as we can get to it, you will have it. Thank you.

APPENDIX
WORKSHOP PARTICIPANTS

ZAIDOON ALSALEEM
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

SAID ASKARI
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

LEE BALDWIN
COLUMBINE INTERNATIONAL, LTD.
5441 MERCHANT CIRCLE
PLACERVILLE, CA 95667

DR. ING HANS-PETER BARBEY
SLT LINING TECHNOLOGY
POLLHORNWEG 17
D-2102 HAMBURG 93, GERMANY

JEFF BLUM
STS CONSULTANTS
3340 RANGER ROAD
LANSING, MI 48906

TOM K. BOYD
ATEC ASSOCIATES
11121 CANAL ROAD
SHARONVILLE, OH 45241

DAVID BURY
ENVIRONMENTAL PROTECTION INC.
P.O. BOX 333
MANCELOWA, MI 49659

MARK CADWALLADER
GUNDLE LINING SYSTEMS
GUNDLE ROAD, 1340 E. RICHEY ROAD
HOUSTON, TX 77073

DANIEL CAMPBELL
OHIO EPA
40 S. MAIN STREET
DAYTON, OH 45402

DAVID A. CARSON
U.S. EPA - RREL
26 W. MARTIN LUTHER KING DRIVE
CINCINNATI, OH 45268-3001

JERRY CHRISTOPH
NATIONAL SEAL CO.
1245 CORPORATE BLVD.
AURORA, IL 60504

MICHAEL E. CLARK
HAZWRAP-MARTIN MARIETTA ENERGY SYSTEMS, INC.
216 OCMULGEE COURT, BLDG. 300
ROBINS AIR FORCE BASE, GA 3109

BILL CORBET
HULS AMERICA, INC.
TURNER PLACE, P.O. BOX 365
PISCATAWAY, NJ 08855-0365

GREG CORCORAN
DREXEL UNIVERSITY
32ND & CHESTNUT
PHILADELPHIA, PA 19104

JACQUES COTE
SOLMAX GEOSYNTHETICS
1440 JOLIOT-CURIE
BOUCHERVILLE, QUEBEC, CANADA J4B 7L

MIKE COX
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

DEWEY CRIPPS
STAFF INDUSTRIES
DETROIT, MI 48207

STEVE DAVIS
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

ANNETTE DE HAVILLAND
OHIO EPA
P.O. BOX 2198
COLUMBUS, OH 43266

LESTER DEMERS
TEXEL
485 DES ERABLES
ST-ELZEAR, QUEBEC, CANADA G0S 2J0

GARY DETILLO
PALCA LININGS
2624 HAMILTON BLVD.
S. PLAINFIELD, NJ 07080

DICK DICKINSON
INDUSTRIAL & ENVIRONMENTAL PLASTICS
P.O. BOX 4218
MELUCHEN, NJ 08840

SUBIJOY DUTTA
U.S. EPA
401 M STREET,
WASHINGTON, DC 20460

TED DZIERZBICKI
NATIONAL SEAL COMPANY
1245 CORPORATE BLVD, SUITE 300
AURORA, IL 60504

ANTHONY EITH
RUST ENVIRONMENT INFRASTUCTURE
3220 TELLMAN DRIVE, SUITE 300
BENSALEN, PA 19020

MOTAS EMARA
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

LEE EMBREY
WATERSAVER COMPANY, INC.
2850 DIXIE HIGHWAY
WATERFORD, MI 48328

FRANZ ENGEL
BAUVEG AMERICAN INC.
11510 GEORGIA AVENUE, SUITE 340
WHEATON, MD 20902

JERRY FISHER
POLY-FLEX
10 S. 224 TERRY TRAIL
HINSDALE, IL 60521

J.W. GAGNON
J.W.G. & ASSOCIATES
CANADA

SKEET GRAY
BROWNING-FERRIS INDUSTRIES
8607 ROBERTS DRIVE, SUITE 100
ALLART, GA 30350

JOHN GRAMLICH
PALCO LININGS
2624 HAMILTON BLVD.
SOUTH PLAINFIELD, NJ 07080

CLARK GUNNES
RESICON
BOX 677
SUNAPEE, NH 03782

ADEL HADDAD
QUANTUM-USI DIVISION
11530 NORTHLAKE DRIVE
CINCINNATI, OH 45249

JOHN Q. HARGROVE
BROWNING-FERRIS INDUSTRIES
757 NORTH ELDRIDGE
HOUSTON, TX 77079

ROBERT HARTLEY
SAIC
635 WEST 7TH STREET
CINCINNATI, OH 45203

SCOTT HEIDENRDICH
OHIO EPA
347 NORTH DUNBRIDGE ROAD
BOWLING GREEN, OH 43402

GHODRAT HIADARI
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

STEVEN HOBBS
CONCORD GEOTECHNICAL
26 S. MAIN STREET
CONCORD, NH 03301

EDWARD HOLLOS
JOYCE ENGINEERING
4660 S. LABURNUM AVENUE
RICHMOND, VA 23231

JOHN T. KENDALL
CHEMICAL WASTE MANAGEMENT
35251 OLD SKYLINE ROAD
KETTLEMAN CITY, CA 93239

TERRY L. KEPHART
FULLER, MOSSBARGER, SCOTT & MAY ENG., INC.
1409 NORTH FORBES ROAD
LEXINGTON, KY 40511

JOHN KERR
ATEC ASSOCIATES
11121 CANAL ROAD
CINCINNATI, OH 45241

DARRELL KILLIUS
HIMONT USA
800 GREENBANK ROAD
WILLMINGTON, DE 19808

ROBERT M. KOERNER
DREXEL UNIVERSITY
33RD & LANCASTER, BLDG 10, WEST WING
PHILADELPHIA, PA 19104

GARY KOLBASUK
NATIONAL SEAL
1255 MONMOUTH BLVD.
GALESBURG, IL 61401

MOHAMMAD KORKZAN
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

JENNIFER KURKO
STATE OF OHIO

ROBERT E. LANDRETH
U.S. EPA - RREL
5995 CENTER HILL AVENUE
CINCINNATI, OH 45224

BILL LINDSEY
QUANTUM-USI DIVISION
11530 NORTHLAKE DRIVE
CINCINNATI, OH 45249

MARK A LITKENHUS
FULLER, MOSSBARGER, SCOTT & MAY ENGINEERS
1409 NORTH FORBES ROAD
LEXINGTON, KY 40511

DAVID LOUCKS
COLUMBIA GEOSYSTEMS
1415 28 ST., NE
CALGARY, ALBERTA, CANADA

LANCE MABRY
INDIANA DEPT. OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206

ROBERT E. MACKEY
POST, BUCKLEY, SCHUH AND JERNIGAN
1560 ORANGE AVENUE, SUITE 700
WINTER PARK, FL 32789

JOHN T. MASSEY-NORTON
AMERICA ELECTRIC POWER
1 RIVERSIDE PLAZA
COLUMBUS, OH 43215

MIKE MATHIESON
GUNDLE LINING
19103 GUNDLE ROAD
HOUSTON, TX 77073

DAVE McNEIL
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

STEVE MENOFF
CHAMBERS DEVELOPMENT CO., INC.
10700 FRANKSTOWN ROAD
PITTSBURGH, PA 15235

ROBERT T. MEYER
BLAZOSKY ASSOCIATES, INC.
205 E. BEAVER AVENUE, SUITE 201
STATE COLLEGE, PA 16801

STEVEN MOLNAR
EDISON WELDING INSTITUTE
1100 KINNEAR
COLUMBUS, OH 43212

MATTHEW D. NEELY
WASTE MANAGEMENT
RD #9, BOX 317
YORK, PA 17402

JOSEPH O'CONNELL
NTH CONSULTANTS, LTD.
38955 HILLS TECH DRIVE
FARMINGTON HILLS, MI 48331

JEANNE OGDEN
OHIO EPA
40 S. MAIN STREET
DAYTON, OH 45402

KEN PAINE
HY-TECH PRODUCTS, INC.
4523 BROOKPARK ROAD
CLEVELAND, OH 44134

IAN PEGGS
I-CORP
5920 NORTH OCEAN BLVD.
OCEAN RIDGE, FL 33435

STEVE PEKERA
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

BOB PHANEUF
NY STATE DEC, DEPT. OF SOLID WASTE
40 WOLF ROAD
ALBANY, NY 12233

DAVID POWELL
FLUID SYSTEMS
32 TRIANGLE PARK
CINCINNATI, OH 45246

DIPL. ING ROLF PREUSCHMANN
BUNDESANSTALT FUR MATERIALFORSCHUNG
UNTER DEN EICHEN 87,
D-1000, BERLIN 45, GERMANY

SYAMALA RAMAN
INDIANA DEPT. OF ENVIRONMENTAL MGMT.
105 S. MERIDIAN STREET
INDIANAPOLIS, IN 46225

CHARLES REDDING
SLT NORTH AMERICA
200 S. TRADE CENTER PARKWAY
CONROE, TX 77385

ANTHONY "TONY" REEVES
HURT & PROFFITT, INC.
P.O. BOX 25
CLOVER, VA 24534

LJILJANA RODIC
TU DELFT UNIVERSITY
DELFT, NETHERLANDS

FRED ROHE
ENVIRONMENTAL PROTECTION, INC.
P.O. BOX 333
MANCELONA, MI 49659-0333

STEVE ROWE
ATEC ASSOCIATES
11121 CANAL ROAD
SHARONVILLE, OH 45241

GREG SCALES
NICOLON
3500 PARKWAY LANE, SUITE 500
NORCROSS, GA 30092

KURT SHANER
CHAMBERS DEVELOPMENT CO., INC
10700 FRANKSTOWN ROAD
PITTSBURGH, PA 15235

JEFF A. SHEPHERD
BROWNING-FERRIS INDUSTRIES
757 NORTH ELDRIDGE
HOUSTON, TX 77079

MAHIRU SHETTIMA
J&L ENGINEERING, INC.
938 SOUTH CENTRAL AVENUE
CANNONSBURG, PA 15317

FRANK SINCLAIR
SINCLAIR EQUIPMENT COMPANY
6686 A MERCHANDISE WAY
DIAMOND SPRINGS, CA 95619

MARK SMOLINSKI
PSI
11381 LANDON LANE
CINCINNATI, OH 45246

LYNN SOWERS
OHIO EPA NORTHEAST DISTRICT
2110 E. AURORA RD.
TWINSBURG, OH 44087

ED STAFF
STAFF INDUSTRIES
DETROIT, MI 48207

LAURA STEADHAM
INDIANA DEPARTMENT OF ENVIRON. MGT.
105 SOUTH MERIDIAN STREET
INDIANAPOLIS, IN 46206-6015

JIM STENBORG
CHAMBERS DEVELOPMENT CO., INC
10700 FRANKSTOWN ROAD
PITTSBURGH, PA 15235

BILL M. STRACHAN
RUMPKE SYSTEMS
10795 HUGHES ROAD
CINCINNATI, OH 45251

FRED STRUVE
GUNDLE LINING
19103 GUNDLE ROAD
HOUSTON, TX 77073

GHASSAN TAFLA
OHIO EPA
347 NORTH DUNBRIDGE ROAD
BOWLING GREEN, OH 43402

HENRY TROUNSTINE
ROCHEUX INTERNATIONAL
2587 GRANDIN ROAD
CINCINNATI, OH 45208

RANDY UNDERWOOD
CH2M HILL
P.O. BOX 4400
RESTON, VA 22090

PAUL A. VALLADARES
EMCON BAKER SHIFLETT
3408 N. BEND ROAD
CINCINNATI, OH 45239

DAVE VLADIC
CHAMBERS DEVELOPMENT CO., INC
10700 FRANKSTOWN ROAD
PITTSBURGH, PA 15235

BILL WALLING
SLT NORTH AMERICA, INC
200 SOUTH TRADE CENTER PARKWAY
CONROE, TX 77385
MARK WAYNE
POLYFELT, INC.
P.O. BOX 727
EVERGREEN, AL 38401

DOUG WELLS
SERROT CORP.
5401 ARGOSY DRIVE
HUNTINGTON BEACH, CA

CARLTON WILES
U.S. EPA
5995 CENTER HILL AVENUE
CINCINNATI, OH 45224

STEVE WINTHEISER
NATIONAL SEAL CORP
167 ANDERSON ROAD
EVANS CITY, PA 16033

MARK WOLSCHOR
ENVIRONMENTAL PROTECTION INC.
P.O. BOX 333
MANCELONA, MI 49659

JOHN WORKMAN
LAIDLAW WASTE SYSTEMS
655 METRO PLACE, S, SUITE 500
DUBLIN, OH 43017

GREG A. YAPLE
COLUMBINE INTERNATIONAL LTD.
5441 MERCHANT CIRCLE
PLACERVILLE, CA 95867

EDWARD ZEMMEL
GUNDLE LINING
19103 GUNDLE ROAD
HOUSTON, TX 77073

GLEN N. ZENOR
J.P. STEVENS
395 PLEASANT STREET
NORTH HAMPTON, MA 01060

DAGMAR ZIEGLER
WEGENER NORTH AMERICA
231 FRONTAGE ROAD, UNIT 12
BURR RIDGE, IL 60521

DONNA ZUNT
U.S. EPA
5995 CENTER HILL AVENUE
CINCINNATI, OH 45224

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United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

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