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PREDICTING AND MITIGATING CORROSION RELATED DAMAGE IN
GEOTHERMAL FACILITIES, PHASE-I

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DOE/DE-FC07-98ID13656

**PREDICTING AND MITIGATING
CORROSION RELATED DAMAGE
IN
GEOTHERMAL FACILITIES, PHASE-I
(PROJECT # DOE98-A)**

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FINAL TECHNICAL REPORT

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UNDER COOPERATIVE AGREEMENT #DE-FC07-98ID13656**

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EXECUTIVE SUMMARY

Background

Corrosion related damage (CRD) is probably the most important and costly damage mechanism for components operating in geothermal fields. This problem is further complicated as steam chemistry in such fields changes continuously with season, time, and load. Unfortunately, such changes are not predictable. The problem is further complicated in the area where early condensate (first moisture) forms. The chemistry of these first droplets is significantly different from that of bulk steam and this, again, cannot be predicted with reasonable accuracy. Therefore, a formidable challenge facing the geothermal field operators remains in knowing the chemistry of the condensate and, more importantly, how it affects specific field equipment such as rotor, piping, valves, etc.

In order to reduce the cost of maintenance and operation (O&M) and increase the reliability of such components, methods and tools will be necessary to monitor and predict conditions leading to CRD of specific components.

Objectives

The overall goal of this project was to develop methods that can be used by geothermal plant operators to reduce O&M costs associated with CRD of plant components. For this purpose, the following specific objectives were established for this project:

1. Develop techniques and tools to measure the "corrosion potential" of condensing steam.
2. Investigate the existence of a relationship between early condensate chemistry and stress corrosion cracking (SCC) of specific materials.
3. Investigate the existence of a relationship between early condensate chemistry and bulk steam chemistry measurements.
4. Identify preventive and/or mitigative techniques for reducing SCC of rotor material operating in The Geysers plants.
5. Develop methods and tools to monitor conditions which lead to pitting of a specific material operating in early condensate regime.

Methods

This project was divided into two separate but dependent sub-projects. The first project (Part I) expanded on earlier work [1-2] to develop tools and conduct long-term testing to help identify conditions leading to stress corrosion cracking of rotor steel and investigate relationships amongst various measured properties. For this purpose, the existing SCC lab was reconfigured for the new testing. Then, in a long and continuous testing program, temperatures, pressures,

strains, pH's, conductivity, and corrosion potentials were measured. Steam samples were gathered and measured using an outside laboratory. These measurements were used to explore changing steam chemistries, conditions leading to SCC of rotor steel, and the relationships among various measurements. Also, in this part of the project a new and promising technique for mitigating SCC of rotor steel, and possibly CRD of many other components, was identified.

The second part of the project (Part II) addressed the development and testing of tools/techniques for detecting pitting events in condensing geothermal steam. This is particularly important because SCC, as well as other forms of CRD, are preceded by periods of pitting. This suggests that if plant operators can monitor pitting events and take preventive measures when critical rates of pitting are being observed, they can prevent SCC (and maybe CRD) of their components. For this part of the project, the initial concept for the detection of pitting events based on electrochemical noise monitoring developed earlier [2] was expanded. Tools and techniques were developed to monitor such noise and to detect such events. Lab testing was conducted to evaluate and improve these tools and techniques. Once successful lab testing had been performed, a field testing program was started to monitor and detect pitting events in the early condensate regime of geothermal steam. This testing was conducted in the same CRD lab.

Results

The objectives set forth for this project were achieved. The following list summarizes the results of the project:

1. A method and required tools were developed to measure the Corrosion Potential (CP) of condensing steam in geothermal fields.
2. During the testing, no crack growth of the modified wedge opening load (MWOL) coupons was measured and therefore no relationship could be established between SCC growth and any of the other measured parameters including CP of the rotor steel.
3. Measurements and comparison of bulk and early condensate chemistries did not reveal any relationship between them. This implies that in order to predict CRD and protect components in the early condensate regime against CRD, one needs to measure the chemical composition of the early condensate or its effect on metal parts directly.
4. In addition to mitigative methods against CRD of geothermal plant components identified in an earlier work [2], a new and potentially very cost effective method was proposed. In this method, a proprietary chemical is added to the superheated steam which will segregate into the steam's early condensate and protect metallic components by forming a moisture repellent film. A testing program was identified to evaluate this technique for its effectiveness to protect rotor steel against SCC.
5. Tools and techniques were developed to continuously monitor for and detect pitting events occurring on specific materials operating in the early condensate regime of geothermal steam. These methods are based on continuous measuring of electrochemical noise between specially designed electrodes, using specially designed electronics and software, and detecting pitting event signatures from the noise.

Conclusions/Recommendations

The SCC lab was upgraded and used for testing of conditions leading to SCC and pitting of rotor steel in the early condensate regime of geothermal steam in The Geysers steam field. Operating conditions, crack size, various parameters of steam chemistry were measured on a continuous basis during the test. Corrosion potential measurements and electrochemical noise measurements were also conducted. This project showed that testing in such an environment is feasible and concluded that continuous monitoring of steam conditions is needed to detect and prevent conditions leading to CRD of components. This project also developed tools and techniques for continuous monitoring of corrosion potential and detection of pitting events.

We believe the work performed and results obtained in this project have established the basic principles for developing commercial tools for continuous CP measurements and a pitting event detector for early condensate regimes of geothermal fields. Such tools can also be used in single phase liquids for the same purposes. We recommend (and plan) to continue this current work to develop and demonstrate the commercial versions of these products. We also recommend that a project be established to investigate the feasibility of the new mitigative technique for elimination of SCC in geothermal rotors. A project for this purpose has been proposed to Calpine Corp.

PART I: CRD MEASUREMENT REPORT

This part of the report presents the methodology and results from testing to detect and monitor steam conditions leading to corrosion related damage of components operating in condensing geothermal steam. The testing and results presented here are for conditions leading to stress corrosion cracking of rotor material in The Geysers geothermal field.

This part of the report consists of the following sections:

- Section I-1: Introduction
- Section I-2: CRD Testing
- Section I-3: Preventive Techniques
- Section I-4: Conclusions and Recommendations
- Section I-5: Acknowledgements and References

Section I-1: Introduction

Background

Corrosion related damage (CRD) in geothermal fields is the primary factor which reduces a plant's safety, reliability, and maintenance and hence its profitability. CRD can manifest itself in many forms including stress corrosion cracking (SCC), erosion/corrosion (E/C), general corrosion (GC), and corrosion fatigue (CF). Difficulties associated with predicting and mitigating CRD include variations in steam chemistry with field, season, injection pattern, plant load, time, and equipment considerations. Furthermore, CRD is more prevalent in areas where the steam's early condensate (first moisture) forms. To increase the profitability of geothermal power plants, prediction and mitigation of CRD becomes a high priority. In response to this need, an approach was conceptualized with the goal of developing methods and tools for predicting and mitigating CRD of geothermal plant components. This report presents the methodology and results from Phase I work in which the conditions leading to the SCC of turbine rotor material were evaluated and methods and tools for continuous monitoring of early condensate steam were developed.

Objectives

The research project described herein was initiated with support from the Department of Energy, Idaho Operations (Grant #DE-FC07-ID13656). The overall project goal was to increase geothermal plants' profitability by increasing reliability and efficiency of plants and reducing their operation and maintenance costs.

The specific objectives of this current work (Phase I) were the following:

- Develop an understanding about conditions leading to SCC of the turbine rotor materials operating in The Geysers geothermal field.
- Develop tools and methods for continuous measurement of the corrosivity of early condensate steam.
- Propose alternative mitigative solutions to reduce rotor SCC.

Section I-2: CRD Testing

Testing Activities

A test program and procedures were developed to conduct testing for the stress corrosion cracking response of rotor steel in condensing geothermal steam. Attachment #I-1 contains the procedure used for this test. In this section, a summary of major activities is presented.

SCC testing in simulating steam conditions in the turbine rotor of a geothermal plant

A portable field lab, developed earlier [1-2], was modified and used for simulating early condensate steam conditions in a geothermal power plant. Figure I-1 shows the process and instrumentation diagram (P&ID) of this lab. The lab was instrumented with pressure, temperature, and flow meters; a number of modified wedge opening load (MWOL) coupons for measuring crack size; pH and conductivity probes for measurements of bulk steam conditions; and a new device for measuring corrosion potential of early condensate steam.

Figure I-1: CRD research lab P&ID

The lab was initially installed near the de-superheating injection ports of The Geysers Unit 20, but later it was moved to wellhead #GDCF1528. A testing program was implemented in which various parameters were measured continuously. Testing began in August of 1999 and continued until May of 2000. In addition to lab measurements, steam samples were obtained and analyzed for water vapor, carbon dioxide, hydrogen sulfide, ammonia, argon, nitrogen, methane, hydrogen, chloride, and boron. During this testing program a number of problems

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(such as failure of lab components and instruments, and power/communication supply issues) were encountered which led to 3 extended lab shutdowns of more than two weeks and 11 short duration (1-14 days) shutdowns. However, while these shutdowns were undesirable from economic and scheduling point of view for the testing, they reflect the conditions encountered in real field operation which this testing program was trying to simulate.

Test History

The following table describes, chronologically, the events that transpired during the CRD testing period:

Table I-1: CRD research lab test history log

Date		Event
From	To	
9/9/98	9/22/98	Lab delivered to Unit 20 Separator Site and connected to utilities.
11/16/98	12/21/98	Lab Relocated to Well GDCF-1528 and connected to utilities.
1/7/99	2/2/99	Lab Systems Function Tests with Steam Flow
2/3/99	2/5/99	Main Steam Piping Failures Discovered
2/8/99	3/10/99	Piping Repairs Completed
3/12/99	3/20/99	Function Tests Resumed With Steam Flow
3/25/99	3/29/99	Coupons Installed and "Official" Testing Begun
3/30/99	3/30/99	HP Voltmeter Fails. Lab Shut Down for Repair
3/31/99	8/16/99	Lab Shut Down due to transfer of ownership of The Geysers from PG&E/UNOCAL to Calpine Corp.
8/17/99	12/26/99	New Coupons Installed and new "Official" Testing Begun
9/14/99	-	HP Voltmeter Fails
9/26/99	-	Load Bolt Strain Gage #2 Fails
9/27/99	-	Load Bolt Strain gage #1 Fails
12/27/99	1/27/00	Lab Shut Down for Y2K and for piping repairs
2/1/00	2/16/00	Lab Restarted and testing resumed.
2/17/00	3/6/00	Lab Down due to Power Outage and High Sump Level Alarm
3/7/00	5/9/00	Lab Restarted and testing resumed
3/7/00	-	Load Bolt Strain Gage #3 Failed
3/8/00	-	Load Bolt Strain Gage #4 Fails
5/9/00	-	WOL Coupons removed; CRD testing completed

Test Results

Detailed testing results are given in attachments to this report. The following table describes the organization of results given in the attachments.

Table I-2: Attachments description

Attachment No.	Results Given
I-2 (a)	<ul style="list-style-type: none"> • Lab Operation History • Instrumentation Function History • Lab Operating Parameters
I-2 (b)	<ul style="list-style-type: none"> • Lab Steam and Condensate Chemistry Parameters <ul style="list-style-type: none"> ➢ Well Head Chemistry ➢ Bulk Condensate pH, Conductivity, & Corrosion Potential ➢ Test Chamber Coupon Corrosion Potential ➢ Test Chamber "Switch" Corrosion Potential
I-2 (c)	<ul style="list-style-type: none"> • WOL Coupon related data (strain gage, load and temperatures)

Discussion of Results

Evaluation of the collected data shows the following results:

1. Lab operational history and measured operating parameters (see Attachment 2) show the following:
 - During this testing program, most instrumentation and controls worked properly.
 - The lab operated during most of the testing program. Out of the 267 days of the testing period, the lab operated successfully for 181 days with data being collected. During the remainder, either the lab was shut down for repairs/modifications, the data acquisition system had problems, or steam or power supply were interrupted.
 - Wellhead (main) steam pressure varied by a significant amount during the testing. Daily pressure cycles were observed which can be related to plant loads. The main steam pressure varied from about 50 psi to as high as 110 psi. The pressure in the test chamber varied less, from a bit under 20 psi to about 35 psi.
 - The main steam temperature fluctuated as much as 50°F. However, for the most part, the temperature fluctuations were quite small (less than 20°F). The temperature in the test chamber remained relatively more constant with average fluctuation of less than 10°F. The chemistry chamber temperature stayed around 60-80°F throughout testing except for two short periods where the temperature reached as high as 200°F.
2. Steam chemistry measurements were taken by various methods including:
 - Well head chemistry measurements by iso-kinetically sampling main steam and conducting chemical analysis in a lab (NCPA). This testing was conducted at a rate of about 1 sample per month.
 - Bulk condensate chemistry measurements for pH, conductivity, and corrosion potential. This testing was conducted continuously at 15-minute intervals using commercially available probes.

- MWOL coupon (inside test chamber) corrosion potentials using specially designed CP probes attached to the coupons.
- "Switch" probe (inside test chamber) corrosion potentials were measured using specially designed probes.

Selected results are reported in Attachment II-2. These results indicate a very dynamic steam field where many steam parameters change. The following discussions apply to various measurements.

a) Well Head Chemistry Measurements:

Figure I-2, which shows chloride, boron and ammonia measurements in a 10 month period, indicates that chloride levels vary by about an order of magnitude. As the chloride level in the steam has a significant impact on CRD of components (specifically SCC of rotor steel), this figure indicates that steam chemistry can fluctuate between being very aggressive to being benign for specific components. Measurements of boron and ammonia, which are believed to impact SCC, also indicate changes of order of magnitude or more for the same period.

Figure I-2: Wellhead chemistry for ammonia, boron, and chlorides

These results suggest that one can predict and prevent CRD of various components by continuously monitoring/measuring these constituents and taking the appropriate mitigative action. One may further argue that changes in these constituents can be related to specific

field conditions, plant loads, and seasons. Unfortunately, measurements of steam constituents are very costly and time consuming (e.g. some tests can take few hours) hindering the former suggestion impractical. The latter argument may have some credence and it requires a systematic and large research/testing program where various well's chemistries are sampled and tested routinely and results are related to field conditions. Such a testing program was outside the scope of the current study; however, we believe such a program can have significant benefits to well management of geothermal plants.

Another interesting observation from this data and the lab testing history (Table I-1) may be made as follows:

Facts:

- Lab components made of stainless steel (piping, valves and wire shields) had a large rate of failure after moving the lab from Unit-20 separator to the wellhead in December 98 and resuming operation in February 1999. Some of these failures were observed only after few days of testing.
- Lab piping failure was metallurgically proved to be SCC related. Examination of wire shield showed signs of SCC as well.
- The same lab components had survived a one-year testing at the Unit-20 separators where steam had been "washed" and probably contained far less chlorides.
- Steam chemistry measurements show high chloride levels during February (of 2000).

Observation:

If one assumes that the steam chemistry is seasonal and cyclic, most failures occurred during the period when the chloride levels were high (as measured a year later). Therefore, one may argue that damage to plant components are also seasonal (or at least vary). Hence, by monitoring and detecting conditions causing damage to the components, one can operate the units with higher reliability and at lower O&M costs.

After the initial failures, most lab components were upgraded to titanium and Alloy 600 (a nickel-based superalloy) which prevented further failures.

b) Bulk steam chemistry (pH, conductivity, and corrosion potential):

These measurements were taken continuously at 15-minute intervals inside the chemistry chamber of the lab. Unfortunately, due to instrument problems only limited data was collected. This limited data, however, indicates that a clear relationship between these parameters cannot be established. Attempts to correlate measured pH (a relatively easy measurement) to the corrosion potential of the condensing steam inside the test chamber (see Fig. I-3) were not successful. Therefore, it may be concluded that bulk steam chemistry measurement does not provide desired information about the early condensate chemistry.

Figure I-3: Early condensate CP (from "Switch") vs. bulk condensate pH

c) CP measurements of early condensate steam

These measurements were taken both by the CP probe connected to MWOL coupons and the new "Switch" probes. Results (Attachment #I-2) show large variations during testing which are indicative of varying steam conditions. It is also of interest to note that after each lab shutdown, the CP measurements undergo a large change before settling to their "steady-state" condition. We believe this is caused by the introduction of oxygen into the testing chamber during shutdown periods. This may mean that chemistry transients during startup/shutdowns could affect the tendency for CRD of various components. Finally, a review of the collected data compared to method of collection indicates that continuous CP measurements are feasible once the proper instrumentation is used. For this testing program, we found the most reliable information to be gathered from the properly positioned "switch" assembly.

3. Continuous and on-line crack growth measurements using special design bolt strain gages [2] were conducted. Results of these tests are presented in Attachment #I-2. Unfortunately because of the aggressive environment of well steam, these gages failed at various times during testing. Out of four gages, two of them failed early in the testing program. The other two also failed before testing was complete despite preventive measures taken after the failure of the first two gages. We determined the root cause of these failures and have designs which will eliminate future failures if such activity is undertaken.

Figure I-4 shows bolt loads as a function of time for the four gages. The rapid change in the bolt load prior to their gage failure is believed to be due to gage problems (moisture introduction) and hence that part of data was not used. This figure also shows chloride and boron measurements taken during the testing.

Figure I-4: Strain gage data with temperature compensation

Table I-3 below lists measured crack sizes for each MWOL coupon before and after testing. These measurements are performed using compliance technique using a 20Kip MTS servo-hydraulic machine for applying and measuring opening load and an extensometer for measuring the opening (COD). Geometry of the MWOL coupons was also measured before and after exposure to testing for establishing crack sizes. This technique has been described in earlier work [2].

Table I-3: Pre- and Post- exposure MWOL coupon crack sizes.

Coupon ID	Pre-exposure crack size (in)	Applied K _I (Ksi-in ^{1/2})	Exposure (months)	Post-exposure crack size (in)	Approx. crack growth (in)
SG-1	0.9375	26.25	~10	0.908	None Detected
SG-2	0.9888	30.74	~10	1.0375	None Detected
SG-3	0.893	30.36	~10	0.875	None Detected
SG-4	1.0178	38.22	~10	0.934	None Detected

Note: The error tolerance in measuring crack size is about 0.050".

As there are potential errors and inaccuracies with the measurement of geometry, loads and COD, and there are inaccuracies in calculation methodology for crack size from these measured values, a tolerance on crack size measurement was estimated to be about 0.050". Once this tolerance is applied to the measure crack sizes before and after the testing, we concluded that there is not any evidence of crack growth during the testing. This is supported by measured loads via strain gages 3 and 4 where no load change was detected. Furthermore, coupon #4 was loaded to failure and the examination of the surfaces showed no sign of crack growth.

Therefore, we concluded that there was no SCC growth on the rotor steel under applied conditions during this testing. This may mean one or a combination of the following:

- That the rotor steel is tolerant against SCC under the exposed conditions (chemical and applied loading conditions),
- That the incubation time for initiation of SCC under the tested conditions is longer than the testing period,
- Any crack growth was within the measurement tolerance and therefore undetectable.

Section I-3: Preventive Techniques

In general, a combination of three parameters determines if a component will age or be subjected to CRD. These are:

- The materials of the component,
- Operating stresses/strains,
- Environmental conditions.

To prevent CRD to a specific component, one needs to start with the type of CRD. In this specific case of stress corrosion cracking of rotor steel, all three parameters play important roles. Therefore, conceptually, one has the following options to prevent SCC to rotor steel:

- 1) Change the rotor material to one less susceptible to SCC in the given environment,
- 2) Reduce operating stresses at critical areas by redesign of geometry, and/or
- 3) Protect the susceptible material from the environment or change the environment.

The first two options are usually considered during the original design phase of the component. Furthermore, their application for the current SCC problems of geothermal rotors seems to be impractical due to their high cost. This leaves the third option, preventing the environment from reaching the material and/or changing the environment. The current approach used at The Geysers – de-superheating – is an example of the third option whereby the chemistry of the condensate is changed before it reaches the rotor. Unfortunately, this current technique has a number of disadvantages including:

- The correct amount of de-superheating is more of an art than science and hence the operators are not sure if they are over or under de-superheating the steam.
- De-superheating has historically shown an improvement in the reduction of SCC occurrences but has not eliminated all of them.
- De-superheating at any level reduces available energy of the steam by as much as 3% and therefore it has a large economic impact on the cost of produced energy.

Other approaches have been conceptualized [2] for the third option. These include dry scrubbing, welding of blades to disk, and sealant approach. A recent project [3] evaluated the sealant approach by investigating sealants which can prevent moisture to reach the high stress areas of the rotor disks. Unfortunately, that study found no currently available sealants that can perform the desired function. We are not aware of any activities to evaluate the other two approaches, however, we feel either one (i.e. dry scrubbing or welding option) may lead to elimination of SCC of the rotor steel.

More recently a new process has been suggested where a proprietary chemical (by Chemco Water Treatment Co.) is added to the superheated steam. Upon formation of the early condensate, this chemical is believed to bond to the metal surfaces and repel moisture. In light of the success of a similar approach by this chemical manufacturer on condensate chemistry, it is believed that the proposed approach has a great chance of success for mitigating CRD. Based on this concept, a project was conceptualized where parallel testing of treated and untreated steam

will be conducted. This approach has been proposed to Calpine Corp. and is being considered as Phase-II of this current work.

This solution, if proven, can offer a very low cost and effective alternative to the current de-superheating and hence increase a plant's profitability. For this purpose, Phase II of the current work, the following needs to be performed:

- Search and identify potential inhibitors which can prevent CRD in the early condensate.
- Design and upgrade the existing lab to allow for testing untreated and treated steam simultaneously.
- Develop and conduct testing to demonstrate the effectiveness of the inhibitor.

Section I-4: Conclusions and Recommendations

This project achieved its objectives by:

- Developing methods and tools and conducting long term testing for SCC of rotor steel.
- Developing monitoring devices to continuously measure and potentially detect periods where the chemistry of steam's early condensate causes CRD to specific components such that a preventive action can be taken.
- Identifying a new, cost-effective, mitigative solution which can potentially eliminate rotor SCC.

This work concluded that the steam field and its chemistry undergo large changes during operation. Therefore, the need for preventing CRD of various components is not continuous and in fact periods can exist where no preventive measures may be necessary. This work developed tools that can be used to continuously monitor for such changes in the early condensate regime, thus allowing the operators to design and implement an effective and low cost mitigative approach. For example, these devices/methods can lead to proper de-superheating of steam making sure that over- or under-de-superheating is not taking place. Finally, this work identified a new approach for mitigation of CRD in early condensate regime of geothermal steam. This involved adding a proprietary chemical to the superheated steam which will condense on metallic surfaces and repel moisture from these surfaces.

We recommend that Phase II of this project, where a potential low-cost solution for preventing SCC is to be tested for its effectiveness, be implemented. Results of the Phase II work can be implemented on a large scale to an operating geothermal rotor (Phase III). Future phases of the project, which may involve expanding this technology to other geothermal fields and plant components, are recommended to be investigated.

PART II: PITTING INITIATION DETECTION SYSTEM REPORT

This part (Part II) of the report presents the methodology and results from testing to detect pitting initiation events for a specific material operating in condensing geothermal steam. The testing and results presented here are for conditions leading to pit formation which is a precursor to stress corrosion cracking of rotor material in The Geysers geothermal field.

This part of the report consists of the following sections:

Section II-1: Introduction

Section II-2: Development of the Monitoring Device

Section II-3: Laboratory Testing

Section II-4: Field Testing

Section II-5: Conclusions and Recommendations

Section II-1: Introduction

Background

Corrosion Related Damage occurs in many forms such as SCC, GC, etc. In geothermal steam, where the chemical composition of steam can vary significantly, predicting periods where CRD can occur may only be possible by continuous and direct measurement of steam conditions. This task is not trivial, especially in the early condensate regime of geothermal steam.

One of the most susceptible areas of geothermal plants is their rotors. These rotors, which operate at high stresses and are subjected to the early condensate, may experience stress corrosion cracking. SCC is usually preceded by corrosion pit formation. Pit formation is an electrochemical process which is detectable by electrochemical noise monitoring techniques. In fact, various researchers have successfully detected pitting events in liquid solutions in controlled lab environments [e.g., see 4-7]. However, such an approach has not been demonstrated in a field environment, nor for condensing steam conditions.

In this part of the project, "Corrosion Related Damage Monitoring for Geothermal Plants," a pitting corrosion initiation monitoring device was designed to detect steam conditions leading to pitting initiation for a given material. This development was conducted in the following parts:

- Section 2: Development of the monitoring device
- Section 3: Laboratory testing of the device, refinement of the device, and development of data reduction methods.
- Section 4: Field testing of the refined device and development of data reduction/analysis methods.

This part of the report presents methods and results for the above parts.

Section II-2: Development of the Monitoring Device

This section describes the development of the monitoring device.

Objectives

Major goals and objectives of this work were:

1. Develop a device (probe) that can place two electrodes, one stressed and one unstressed, in close enough proximity such that a droplet of water can bridge the gap, can maintain electrical isolation among all the components, and that all components supporting the electrodes are corrosion resistant.
2. Develop electronics and software to monitor and record the electrochemical noise.

Discussion

An initial design concept for a device capable of monitoring and detecting pitting and SCC events has been given in an earlier work [2]. In this concept, two samples of a given metal, one stressed to a desired level and the other unstressed, are positioned close to each other such that droplets of condensing steam can bridge the gap between them and create an electrical circuit. The electrochemical noise across these two metal samples is continuously monitored, using current or voltage measurements, and events signifying pitting or SCC are detected and interpreted.

Probe Design

After many iterations for the design of this probe, a working design was developed and is shown in Fig. II-1. This device uses two machined coupons of rotor steel in an arrangement such that the two 'electrodes' are connected electrically through droplets of steam condensate. The device was configured with a stressed and unstressed electrode such that the gap between the two electrodes could be adjusted independent of the radius of curvature of the stressed electrode. Materials were selected for the body (Alumina) and hardware (Teflon) to electrically isolate the electrodes and to suppress environmental noise pickup. The bolts were made of titanium for their corrosion resistance and all contact areas were covered by sealants and epoxies to prevent crevice corrosion.

The electrochemical noise generated by this circuit is monitored. From the analysis of gathered data, events signifying the initiation of pits or stress corrosion cracking are detected. By monitoring the rate of such events in a field, one can detect periods when steam chemistry is becoming very corrosive and take preventive measures.

Figure II-1: Probe design for the pitting event detection

Data Acquisition

Data was recorded using a Pentium-based PC running Windows NT™ 4.0. The data acquisition hardware consisted of an IOTech DaqBoard/112A data acquisition card mounted in the computer, an IOTech screw terminal connection card, and an analog signal processing board. A simple program was written which measures voltages using the DaqBoard and writes the data directly to disk. On the signal processing board one current to voltage converter (also referred to as a "zero-resistance ammeter") and one differential instrumentation amplifier were installed.

Figure II-2: Schematic of current to voltage converter

A schematic of the current to voltage converter is shown in Fig. II-2. The output is a voltage V_{out} which is proportional to the current I_{in} flowing into its input. The polarity of the signal is inverted by this amplifier, so the idealized circuit equation is:

$$V_{out} = -R_f I_{in}$$

This circuit presents a very small resistance to the device whose current output is measured, as the high gain of the operational amplifier allows the voltage at the I_{in} terminal to be actively kept equal to zero. Corrosion thus occurs as if the two samples being measured were connected together.

When the tests were first begun, a resistance of 1000 ohms was chosen for R_f . A 1% precision, metal-film resistor was used. Due to the high level of current seen in the first and second tests, this resistor was replaced for those tests with a 100Ω resistor, thus lowering the gain of the amplifier. During the third test, current signals were much smaller, so the 1000Ω resistor was placed back into the circuit.

The differential instrumentation amplifier was a Burr-Brown INA102AG. This integrated circuit contains a set of three operational amplifiers and ratio-matched resistors connected to form a differential amplifier whose output voltage is proportional to the difference between the input voltages. No external components are required to connect the INA102 as a differential amplifier with a gain of 1, 10, 100, or 1000. For the office tests, a gain of 1 was first tried, but in order to improve the signal to noise ratio, a gain of 10 was adopted after a short time. The idealized circuit equation is then:

$$V_{out} = 10(V_+ - V_-)$$

The circuit was connected as shown in the manufacturer's INA102 data sheet.

The differential amplifier was used because of concerns about the large amount of electrical noise being picked up by the DaqBoard's single-ended inputs. It was believed that this noise might prevent the measurement of events caused by chemical activity. The use of the differential

amplifier (instead of reading ground-referenced voltages directly into the DaqBoard) resulted in a reduction of measured electrical noise by a factor of approximately five.

As a prototype, the circuit board, which housed the current and differential voltage amplifiers, was built using soldered-wire-wrap construction on a perforated breadboard. High-reliability sockets were used for all IC's and as jacks for resistors. Power for the circuit was drawn from the ± 5 volt supply provided on the IOTech screw terminal card. The power supply lines were de-coupled by $0.1\mu\text{F}$ mica capacitors located on the breadboard.

Connections from the breadboard to the IOTech screw terminal card were made by unshielded twisted pairs of lines. The connections from the current and voltage amplifiers to the samples were made with 20 gauge shielded 2-conductor Teflon-insulated wires. The shields were connected on one end to the appropriate ground terminals on the amplifier board, and on the other end to grounded samples (except for samples whose voltage was being measured by the differential amplifier). Figure II-3 shows the setup.

Figure II-3: Photograph of typical wiring setup showing IO terminal card and amplifiers

Results

The main objectives for development of the monitoring device were accomplished such that:

1. A device was developed to hold two electrodes in close proximity such that water droplets could bridge the gap. The device also met the objectives for corrosion resistance and noise suppression.
2. The basic architecture for data acquisition was developed.

Section II-3: Laboratory Testing

This section describes lab testing of the designed device, observations and refinements made to the device, and data reduction routines.

Objectives

Major goals and objectives of these experiments were:

1. To identify specific electrical signatures of pitting events occurring to the selected material (rotor steel from The Geysers power plants).
2. To develop hardware and software to monitor the corrosion initiation device continuously and automatically screen data for possible initiation events.

Discussion

Laboratory testing was conducted in three stages, named Test #1, Test #2, and Test #3. All tests followed a general approach but varied in the types of corrosive solutions, device assembly, stress levels, type of data being collected, and the duration of tests. Table II-1 summarizes each of the lab tests performed:

Table II-1: Summary of lab tests

Test ID	Start	Finish	Solution(s)	# of Samples	Data Types	Stress Levels
#1	4/2/99	4/20/99	Condensate w/HCl & H ₂ SO ₄	2		61 ksi
			Tap Water w/HCl & H ₂ SO ₄	2		71 ksi
#2	6/28/99	7/2/99	Tap Water w/HCl & H ₂ SO ₄	4		61 ksi
#3	7/8/99	7/23/99	Condensate w/NaCl	6		Residual stresses

In each of the laboratory tests, the corrosion initiation device (see Section II-2) was submerged in a corrosive solution such that quantitative parameters, i.e. wetted surface area, would remain relatively constant. Samples for each test were made of rotor steel material and were stressed to various levels. The corrosive solutions were selected to cause pitting and corrosion in short periods of time. These solutions were also heated to accelerate corrosion attack on the samples. Finally, at the conclusion of each test lessons learned were used to improve the next test's electrode arrangement and data acquisition methods (e.g. adding corrosion potential measurements). Following a general description of the data acquisition method, details and results for each laboratory tests are provided.

Test Procedures and Results

TEST #1

Test #1 consisted of 2 separate solutions each with a complete corrosion initiation device assembly immersed halfway in it as depicted in Fig. II-4(a) and shown in Fig. II-4(b). Each sample was exposed for 18 days. Attachment II-1 describes the testing parameters and observations for each test sample.

Figure II-4(a): Test #1 setup

Figure II-4(b): Photograph of initial Test #1 setup

This test produced some very pronounced pitting type signals, but after sample examination after the test it was believed that these signals were generated by crevice corrosion on the electrodes where the silicon sealant met the metal. This deduction was made because of the amplitude of the signals and their comparison to the other tests performed later. Figures II-5 (a) and (b) show two typical events from this test.

(a)

(b)

Figure II-5 (a)&(b): Possible events in Test#1
(Note: Times are seconds after 12:09:18, 4/15/99)

TEST #2

Test 2 consisted of 1 solution with a complete dual corrosion initiation device assembly and noble wire corrosion potential probe immersed completely in it as depicted and shown in Fig. II-6. Samples were exposed for 4 days. The solution and monitoring assembly were immersed in a heated water bath at approximately 100°F. Attachment II-1 describes the testing parameters and observations for each test sample.

Figure II-6: Test #2 setup

The appearance of the data – see Figs. II-7 (a) and (b) – suggests that there may have been pitting events taking place, but the noise from the general corrosion signal was large enough to overwhelm the pitting signal. No particular “events” were visible in any of the data. This was probably due to an excessively aggressive solution in which accelerated general corrosion dominated over all other signals.

Figure II-7 (a): Typical voltage signal from Test #2

Figure II-7 (b): Typical current signal from Test #2.

LAB TEST #3

Test #3 consisted of two multi-electrode assemblies immersed in one buffer solution as depicted in Figs. II-8 (a) and (b). Samples were exposed for 15 days. This test did not utilize the ceramic loading jig to create the stressed electrode. Instead, a residually stressed sample was used as the

stressed electrode. The solution and corrosion initiation device assembly were immersed in a heated water bath at approximately 100°F. Attachment II-1 contains more details.

Figure II-8 (a): Test 3 setup.

Figure II-8 (b): Photograph of Test #3 setup.

Figures II-9 (a) and (b) show some definite pitting event characteristics. Along with these events, there was a high level of general corrosion noise which may have masked smaller pitting events.

Figure II-9 (a): Sample event from Test #3.

Figure II-9 (b): Sample event from Test #3.

A general examination of the sample surfaces from this test showed signs of general corrosion, pitting corrosion and surface cracking. Figure II-10 is a photomicrograph of the samples from Test #3 which shows the existence of pits along with surface micro-cracking.

*Figure II-10: Photomicrograph (12.5X) of electrode surface condition
(Note large pit and cracking)*

Summary of Lab Test Results

Three controlled tests were performed in an attempt to characterize the pitting signals electronically and to setup the necessary hardware and software to detect and record these events. Different solutions and sample setups were tried with the final test proving to be the most successful. Metallographic examination of the final test samples revealed pitting and surface micro-cracking; these were the desired results from the test. Data analysis for this test revealed events that could be characterized as pitting. However, it was determined that further refinement of the monitoring electronics and software data screening methods were necessary for more reliable detection of pitting events.

Section II-4: Field Testing

This section describes field testing of the designed device, observations and refinements made to the device, and data reduction/analysis methods.

Objectives

Major goals and objectives of the field testing were:

1. To verify the functionality of the SCC monitoring devices and their monitoring capabilities at The Geysers in a controlled steam environment.
2. To identify specific electrical signatures of pitting events occurring to the selected material (rotor steel from The Geysers power plants).

Discussion

In the field testing, a number of PITS (Pitting Initiation deTection System) probes were placed inside the test chamber. Steam from the wellhead was introduced into the chamber after being cooled to form the early condensate. Figure II-11 shows the placement of some of the PITS probes inside the test chamber.

Figure II-11: Photograph showing "Switch" probes arrangement in the test chamber

Data Acquisition

The signals generated by the PITS probes were measured and recorded with a PC-based data acquisition system. Data from several channels was continuously scanned and recorded to disk files as unprocessed voltage readings. Several channels of data were recorded:

- A zero reference
- Two potentials (voltages) between steel and CP metal electrodes
- Two currents between stressed and unstressed steel electrodes
- Two voltages between stressed and unstressed steel electrodes

The recording computer was a Pentium-based PC running Windows NT. The computer was equipped with an IOTech data acquisition system comprised of a DaqBoard-112/A data acquisition board and a DBK13 differential input voltage signal conditioner. Because of the large signals involved, corrosion potentials between the rotor sample metal and CP electrode were measured directly by the analog inputs of the DaqBoard-112/A. The lower-level corrosion voltages between the stressed and unstressed samples were measured using the differential input signal conditioner, which provided an increased level of sensitivity and improved immunity to electrical noise.

In order to measure the current signal produced by corrosion events, a custom circuit board was built to implement a two-channel 'Zero Resistance Ammeter.' The ZRA is a device which is commonly used for measurements of corrosion activity. It is a simple operational-amplifier current to voltage converter. The feedback resistor R_f in the current to voltage converter determines the gain of the ZRA. For the PITS experiments, metal-film resistors of 1000 ohms were used, providing a 1mA signal for each micro-amp of corrosion current. Figure II-12 shows this arrangement.

Figure II-12: Schematic showing the 'Zero Resistance Ammeter'

Test Results

An immense amount of data was collected during this testing. The collected data from various channels were analyzed using DaDisp™ software, which has the capability of performing many types of signal analyses on large amounts of data. This approach was used to determine effective methods of filtering and process of the data. Figure II-14 shows one such screen from this program where the "raw" signal is shown along with various forms of the filtered and processed data. Attachment II-1 contains selected screen captures of the analyzed data. This work showed

the best method of detection involves a set of filtering (low-pass and high-pass) of the raw data followed by algorithms which detect the "behavior" of the pitting event from the filtered data. This work also showed that conversion of signals to frequency domain, although may be helpful in analyzing the details of a signal, is of limited value in detecting the actual pitting events.

Pitting signals were detected during field testing. Figure II-13 shows some of these events detected during this testing.

Figure II-13: Signal analysis showing pitting events detected by PITS in the field testing

The approach developed through the analysis of the data with DaDisp™ was applied to the gathered data to detect each event. Along with each detected event, a number of parameters were also recorded. These parameters include:

- Date and Time: Date and time of the event.
- Duration: Duration of the event.
- Pitting Charge: The time integral of current for the event. A more detailed description of this term follows.
- Max and Min: Peak values of the signal.

A new term is being introduced in this work as the "Pitting Charge". This value corresponds to the time integral of measured current during an event. As pitting corrosion involves charge transfer between a metal and a solution, the Pitting Charge (PiC) represents the amount of charge being transferred. Therefore the PiC should be related to the volume of material being removed during pitting events which itself is related to the size and number of pits being generated. Further analysis of these data is needed to explore this concept further, to develop algorithms to detect such events on a continuous basis (on-line), and to relate various signal types and the actual pitting event. Unfortunately, this work was outside the scope of this project and could not be conducted because of time and funding constraints.

After analysis of the gathered data, which involved filtering and "sanitation" of the data, a number of potential pitting events were identified. Table II-2 shows some of these events from the field-testing. A listing of detected events during this testing is given in Attachment II-1.

Table II-2: Pitting events detected by PITS in the field testing

Date	Time	Duration	Pitting Charge	Max	Min
2/4/99	11:13:34	167.75	0.0111	0.0002	0.0000
2/4/99	13:12:49	17.24	0.3537	0.0000	-0.0100
2/6/99	11:22:30	172.24	0.0394	0.0006	0.0000
2/6/99	21:21:39	34.50	0.1577	0.0023	-0.0100
2/8/99	13:17:11	167.76	0.0074	0.0001	0.0000
3/13/00	8:26:30	24.25	0.0602	-0.0002	-0.0012
3/13/00	8:27:31	167.76	0.6946	0.0006	-0.0028
3/13/00	8:31:43	42.48	0.1732	-0.0002	-0.0031
3/14/00	11:47:47	60.75	0.3752	0.0003	-0.0040
3/14/00	15:52:34	27.25	0.0565	0.0012	-0.0012
4/17/00	21:09:00	24.25	0.0902	-0.0004	-0.0040
4/21/00	15:18:20	23.01	0.1467	0.0049	0.0005
4/21/00	15:19:10	24.50	0.1223	-0.0003	-0.0049
4/21/00	23:37:37	24.76	0.1204	0.0006	-0.0058
5/8/00	6:09:47	18.27	0.0643	-0.0004	-0.0034
5/10/00	3:44:39	21.01	0.0822	0.0006	-0.0037
5/13/00	19:49:58	27.24	0.1254	-0.0003	-0.0055
5/3/00	20:43:30	24.00	0.0652	-0.0004	-0.0040
5/31/00	1:12:47	134.51	0.4961	0.0034	-0.0024
5/31/00	7:19:13	27.56	0.0891	0.0024	0.0002
5/31/00	8:38:56	19.26	0.0597	0.0024	-0.0018
5/31/00	8:47:37	16.26	0.0545	-0.0004	-0.0018

Figure II-14 shows accumulated PiC over the test duration. This plot shows periods where large changes in this quantity take place representing significant pitting event periods. Along with this curve, chloride levels of bulk steam are also plotted. There is a very good agreement between measured chloride levels and pitting events which supports the fact that the developed pitting detection/monitoring system is capable of detecting periods where CRD of components is taking place.

Figure II-14: Accumulated PiC and chloride levels during testing

Finally, Figure II-15, a photomicrograph of the sample used in this test, shows two large pitted areas and some smaller pits.

Figure II-15: Photomicrograph of a sample showing pits

Section II-5: Conclusions and Recommendations

Methods and tools capable of detecting pitting events were designed, developed and tested in both lab and field environments. These tools and techniques include specially designed electrode systems (probes), electronics for current and voltage measurement, a system for data gathering and storage, and methods for filtering and analysis of the gathered data. The field testing showed periods of high activities for pitting. This agrees with the fact that steam chemistry undergoes large changes over time and that CRD of components occurs during certain critical periods. There was also a very good agreement between the measured chemistry of the steam and the Pitting Charge, which is a measure of pitting events. Therefore, field testing of the PITS devices revealed that the developed monitoring tools and techniques have the capability to detect pitting events in the early condensate regime of geothermal steam. Hence, the feasibility of continuously monitoring for and detection of CRD of the components operating in geothermal fields was shown. The rate of pitting events can be used to measure the pitting resistance of an alloy in a steam environment.

We recommend that this work be continued toward the goal of developing a commercial package capable of detecting CRD and providing alerting mechanisms for the operators of geothermal fields to take mitigative action.

PART III: ACKNOWLEDGEMENT AND REFERENCES

Acknowledgement

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ATTACHMENT I-1
to
PREDICTING AND MITIGATING CRD IN GEOTHERMAL FACILITIES REPORT

OPERATIONAL PROCEDURES
AND
TESTING PLAN
IN
CRD RESEARCH LABORATORY

Project # DOE-98-1

Prepared For:
U. S. DEPARTMENT OF ENERGY

Prepared By:
Material Integrity Solutions, Inc.
Berkeley, CA
AUGUST, 2000

OPERATIONAL PROCEDURES AND TESTING PLAN FOR THE GEYSERS CRD RESEARCH LABORATORY

The CRD Lab is designed to operate automatically and be controlled remotely except for start up and shut down. For start up and shut down the system requires manual control from within the lab. These procedures were developed to assist testing personnel in operating the CRD Lab while maintaining personnel safety and equipment in good operating condition. The following personnel are involved in the operation of the lab:

Name	Telephone No.	Pager No.	Contact in case of emergency
Tom Bahning CALPINE	707-431-6084	707-431-4080	yes
Shawn Bratt MIS	510-594-0300x203	-	yes
Manuchehr Shirmohamadi MIS	510-594-0300x202	510-410-4046	yes
			-

Entry Procedure

1. Upon arrival to lab site perform a visual inspection of lab for anything unusual, i.e. steam leaking from the lab, condensation on windows, ventilation unit not operating, anything that would indicate a failure of a lab component(s).
2. Upon entry to the lab carefully inspect all piping, especially any threaded connections, for signs of leakage. Points of leakage will be made obvious by formation of carbonate. Any significant accumulation of carbonate will require joint repair.
3. While in the lab, observe good operational and safety practices, such as keeping the door unlocked and unobstructed, keeping the ventilation system operational, wearing eye, ear, and hand protection.

Emergency

Emergency situations would be considered those situations when a component failure leads to steam leakage or electrical fire. The lab is equipped with a fire extinguisher. In the event that a component failure occurs during manned operation of the lab the following actions should be followed:

1. For a minor steam leak exit the lab and close main steam supply valve HV31.
2. For a small electrical fire disconnect system power by tripping the circuit breakers in the power panel and use the fire extinguisher to extinguish flame.
3. For a major component failure that endangers personnel safety evacuate the lab at once and notify plant emergency personnel of the situation.

Pre-Start Up Check List

Refer to Lab P&ID diagram while executing the following procedures. The following list should be completed prior to lab connection to main steam.

1. Check main steam supply valve HV31 closed before entering Lab.
2. Check open drain valve HV38 on SCC chamber discharge line to vent system.

3. Check open isolation valve to vent system.
4. Check line starter switch for FAN-10 in 'off' position.
5. Secure power to Lab by energizing all circuits from the 3 phase and 110 VAC circuit panels.
6. Secure power to DAC-7 control computer and launch control and data acquisition program CRD_LAB.VI from the desk top.
7. Check closed needle valve on pressure transmitter P01 supply line from main steam inlet.
8. Check open pressure bleed-off port on pressure transmitter P01.
9. Check operational pneumatic control valve FCV21 and air compressor COMP-13. Set COMP-13 line regulator to 20 psig. Valve operation can be tested from the computer by dragging arrow on setpoint slider and verify valve reaction to command.
10. Check closed injection line valve HV32.
11. Check open valve HV33 on SCC-2 chamber inlet.
12. Check closed and secure, door to SCC-2 Chamber.
13. Check closed needle valve on pressure transmitter P02 supply line from SCC-2 chamber.
14. Check open pressure bleed-off port on pressure transmitter P02.
15. Check open discharge line valve HV35 on SCC-2 chamber outlet.
16. Check secure Swagelok fittings on calorimeter sliding probe between SCC-2 chamber and CAL-3 calorimeter.
17. Check open valve HV34 on calorimeter CAL-3 drain line.
18. Check closed valves HV39 and HV40 on calorimeter CAL-3 vent line.
19. Check closed needle valve on pressure transmitter P03 supply line from calorimeter CAL-3.
20. Check open pressure bleed-off port on pressure transmitter P03.
21. Check open valve HV36 on condenser COND-4 outlet.
22. Check condition of condensate strainer FSC25 on condenser COND-4 outlet.
23. Check secure all chemistry probes in chemistry chamber CHEM-5.
24. Check closed chemistry chamber sample valve HV41.
25. Check operational sump pump PP-8.
26. Check open valve HV37 on SUMP-9 discharge line.

System Start Up

Cold Start

1. Start up lab computer and log in using lab account and password. Start control program CRD_LAB.VI. Verify all channels functional and open flow control valve FCV21 by dragging arrow on setpoint slider to 10 #/hr.
2. Energize condenser fan FAN-10 from line starter by switching it to 'AUTO' mode. From computer user interface press Condenser Fan start button to start the fan.
3. Charge main steam supply line to Lab isolation valve HV31.

4. Crack open main steam supply valve HV31 to begin system pressurization. It is critical to pressurize the system slowly as to not damage the inlet and outlet flow meters FIT15 and FIT16 pressure transmitters. Slowly open valve until system maintains 10 #/hr flow.
5. Close drain valve HV38 on SCC chamber discharge line to vent system.
6. Open calorimeter vent valve HV40.
7. Start FAN-6 by switching to manual mode from the front panel of the VFD controller and set speed to minimum.
8. Purge pressure transmitters P01, P02, and P03 by cracking open their needle valves and allowing steam to blow out the bleed-off ports. After a few seconds close the bleed-off ports and slowly open the needle valves.
9. Verify operational pressure transmitters P01, P02, and P03 on gauge face and on the PC.
10. Slowly open main steam supply valve HV31 to full open.
11. From computer user interface verify that a steady flow rate of 100 #/hr is maintained. Flow rate value can be changed by dragging arrow on setpoint slider. Ensure that valve control is set to "Auto" when changing setpoint.
12. Verify from flow meter FIT16 on SCC-2 chamber discharge line that at least 10% of the inlet flow is passing through the calorimeter CAL-3. Otherwise throttle valve HV35 on SCC-2 chamber discharge line until flow requirements are met.
13. Verify proper condenser operation by monitoring chemistry chamber CHEM-5 temperature, T14. Temperature in the chemistry chamber shall not exceed 150°F. If temperature T14 begins to exceed 150°, there may be too much flow through the condenser. Throttle this flow with condenser outlet valve HV36 and SCC-2 chamber discharge valve HV35. Opening HV35 will reduce the quantity of steam flow to the condenser.
14. Monitor steam quality measurement from the PC. If steam quality is less than 97%, reduce fan speed on FAN-6 until 97% quality is achieved. If 97% quality is not achieved even by setting the fan speed to 0, slowly open valve FCV21 to increase flow until proper quality is achieved. Return to step 12 and check condenser condition and make adjustments to maintain 20 #/hr flow through the condenser.
15. If steam quality exceeds 97%, increase fan speed on FAN-6 until 97% quality is achieved. If 97% quality is not achieved even by setting the fan speed to 60, reduce flow by slowly closing valve FCV21 until proper quality is achieved. Return to step 12 and check condenser condition and make adjustments to maintain 20 #/hr flow through the condenser.
16. From VFD Controller front panel switch to 'AUTO' mode.
17. Lab is now ready for continuous operation.

Warm Start

Starting lab after a temporary shutdown.

1. Open all pressure transmitter bleed-off ports.
2. Open drain valve HV38 on SCC chamber discharge line to vent system.
3. Check open drain valve HV34 on calorimeter drain line.

4. Begin data acquisition and control program on the PC. Verify all channels functional and set flow control valve FCV21 to 10 #/hr.
5. Energize condenser fan FAN-10 from line starter by switching it to 'AUTO' mode. From computer user interface press Condenser Fan start button to start the fan.
6. Crack open main steam supply valve HV31 to begin system pressurization. It is critical to pressurize the system slowly as to not damage the inlet and outlet flow meters FIT15 and FIT16 pressure transmitters. Slowly open valve until system maintains 10 #/hr flow.
7. Once system has equalized close drain valve HV38 on SCC chamber discharge line to vent system.
8. Open calorimeter vent valve HV40.
9. Start FAN-6 by switching to manual mode from the front panel of the VFD controller and set speed to minimum.
10. Purge pressure transmitters P01, P02, and P03 by cracking open their needle valves and allowing steam to blow out the bleed-off ports. After a few seconds close the bleed-off ports and slowly open the needle valves.
11. Slowly open main steam supply valve HV31 to full open.
18. From computer user interface verify that a steady flow rate of 100 #/hr is maintained. Flow rate setpoint can be changed by dragging arrow on setpoint slider. Ensure that valve control is set to "Auto" when changing setpoint.
12. Make adjustments to system if necessary to maintain condenser flow at 20 #/hr and/or steam quality at 0.97. See steps 13 through 15 above.
13. From VFD Controller front panel switch to 'AUTO' mode.
14. Lab is now ready for continuous operation.

System Shut Down

There are two methods of shutdown for the lab: manual and remote. Manual shutdown refers to being present at the lab and remote shutdown refers to control computer shutdown from remote location.

Manual Shutdown is used either for a temporary shutdown to make system adjustments or for an extended shut down.

Temporary Shutdown

1. Slowly close main steam supply valve HV31.
2. Close Main Steam isolation valve upstream of HV31.
3. De-energize condenser fan FAN-10 either from PC or line starter box.
4. De-energize heat exchanger fan FAN-6 from computer user interface and by depressing stop button on front panel of VFD.
5. Terminate data acquisition and system control by stopping the data collection program on the PC.
6. Close all needle valves to pressure transmitters.

Extended Shutdown

(Follow steps 1-6 above)

7. Shutdown control computer.
8. Open valve HV38 to ensure complete system depressurization.
9. Close valves HV35 and HV37.
10. Close vent system isolation valve.
11. Shut off air flow from COMP-13 by backing out regulator valve on air line.
10. Disconnect power to fans, compressor, and sump pump by de-energizing circuits 6 and 7 from power panel 1, and circuits 3 and 5 from power panel 2.

Remote shutdown is used when it is desired to shut the lab down by phone line. A computer with a modem and PC-Anywhere software installed is required for this operation.

1. Dial phone number 707-431-6250 from PC-Anywhere.
2. Once connected to the control computer, set inlet valve to 0, turn off fans 5 minutes later, and verify flows are 0.
3. Notify local plant personnel of shutdown.

TESTING PROCEDURE

Coupon Testing

Coupons- Testing will be done using 4 Modified Wedge Opening Load (MWOL) specimens manufactured from Geysers turbine rotor steel.

Instrumentation- Each coupon will be wired with a load bolt strain gage, corrosion potential probe, and thermocouple. The instrument wires will run from the test coupons to the PC through wire glands on the test chamber. Each coupon has the thermocouple and corrosion probe attached to its surface.

Positioning- Each coupon was positioned in the test chamber so that all will be exposed to the same steam conditions, or as close to it as possible. Prior to testing, the steam condition variation within the chamber was mapped out using the sliding steam extraction probe located between the calorimeter and the test chamber. Once the coupons are positioned the sliding probe was positioned as close to the coupons as possible.

Duration- Monitoring for SCC will be conducted for a 7 month period.

Coated Specimen Testing

Specimens- Testing will be done using 6 Brookhaven Lab supplied carbon steel plates with three different style coatings.

Positioning- Three specimens will be hung inside the test chamber with teflon tubing such that they experience similar moist steam impingement. The remaining three specimens will be placed in the condensate sump such that they remain submerged in condensate for the duration of their test.

Duration- Specimens will be exposed to steam and condensate for a 2 month period.

Chemistry

Chemistry chamber-

Automatic Sampling: The chemistry chamber monitors pH, conductivity of the condensate, and the corrosion potential of the rotor steel in the condensate. Each probe is inserted through the appropriately sized Swagelok fitting on the chemistry chamber and secured. The output from the corrosion potential probe will connect to the HP 3457A voltmeter. The output from the pH probe is connected to the voltmeter through its own pH meter. The conductivity probe is connected to the voltmeter through its conductivity meter. The voltmeter, pH meter, and conductivity meter are located in a small cabinet placed above the chemistry chamber. The voltmeter is connected to the control PC through an RS-488 (GPIB) cable.

The pH probe requires bi-monthly maintenance. The probe must be recalibrated to the meter using pH reference buffer solutions. Refer to the manufacturer's operating manual for more detail.

Manual sampling: A weekly condensate sample is taken from the chemistry chamber using sample line valve HV41. Each sample is evaluated for the following constituents: pH,

chloride, fluoride, acetate, glycolate, formate, nitrite and conductivity. Conductivity and pH from the samples are compared to collected data from the chemistry probes to verify their proper operation.

Data Collection

The control PC data file is written in a comma separated variable (csv) file format. Routine housekeeping is performed to prevent the computer hard drive from becoming full and to verify the quality of recorded data and the proper operation of the hardware associated with the data. The data files are down-loaded weekly from the hard drive and stored on floppy disks for future analysis.

The control programs are stored in directory C:\CRD_Lab\Programs, and data is stored in directory C:\CRD_Lab\Data. Data may be archived in subdirectories of the data directory as needed.

Data is reviewed weekly to verify proper operation of all lab components and identify any instruments that may need recalibration.

Crack growth measurements-

Wol coupon measurements (bolt load, temperature, and corrosion potential) are logged on 15 minute intervals from the data logger.

Pressure & temperature measurements-

Pressure and temperature are logged on a 15 minute interval from the data logger.

Chemistry measurements-

Chemistry measurements are logged on a 15 minute interval from the data logger.

DOE PROJECT DOE88-1 CRD RESEARCH LAB P&ID

DOE Project DOE98-1 CRID Research Lab Electrical Schematic Diagram

Circuit Number	Amps	Volts	Circuit Description
1	20	120 vac	Receptacle A: Computer/Data Logger
2	20	120 vac	Receptacle B: Miscellaneous
3	20	120 vac	Receptacle C: Air Compressor
4	20	120 vac	Lights
5	15	120 vac	Sump Pump - PP8
6	20	208 3ø	Variable Frequency Drive & Fan6
7	20	208 3ø	Condensor Fan - Fan10
8	50	208 1ø	Air Conditioner Unit
9	50	120 vac	120 vac Sub Panel

CRD RESEARCH LAB P&ID COMPONENT DESCRIPTION

Equipment			Instruments		
ID	Description	Size	ID	Description	Range
HX1	Heat exchanger, tube in shell.	1/2" pipe, 3" shell, 25'L	P01	Steam Inlet	0-200 psig
SCC2	SCC test chamber	16"OD x 24"L, SS	P02	SCC2 chamber	0-150 psig
CAL3	Flash Calorimeter	4"D Sch40S x 12"L	P03	Calorimeter CAL3	0-30 psia
COND4	Condenser, tube in shell, 20 #/hr.	(4) 5/8"OD tube, 5" shell 39'L	P04	Chem chamber	30 in Hg-30 psia
CHEM5	Chemistry chamber	2"D Sch40S x 12"L	P05	Inlet to SCC2 chamber	0-100 psig
FAN6	Fan for HX1, variable frequency	264 scfm @ 19.8 in. wg. (143 cfm)	FTI15	Steam inlet flow, diff. pressure	0-150 in. H ₂ O
DAC7	Data acquisition and control	Pentium II Windows NT PC, HP-IB voltmeter, Orion conductivity meter,	FTI16	Steam discharge flow, diff. pressure	0-150 in. H ₂ O
		Orion pH meter	T11	Steam inlet, RTD	32-345 F
PP8	Sump pump	29 gpm @ 10 psig	T12	SCC2 chamber, RTD	32-345 F
SUMP9	Condensate reservoir	40 gallon	T13	Calorimeter CAL3, RTD	32-345 F
SUMP9A	Condensate overflow reservoir	110 gallon	T14	Chem chamber, RTD	32-345 F
FAN10	Fan for COND4	955 scfm @ 16.3 in. wg. (394 cfm)	TC wol1	Test coupon A1, TC type T	32-500 F
COMP13	Air compressor for FCV21	1/2 hp, 2.1 cfm @ 40 psig	TC wol2	Test coupon A2, TC type T	32-500 F
			TC wol3	Test coupon A3, TC type T	32-500 F
			TC wol4	Test coupon A4, TC type T	32-500 F
Piping					
ID	Description	Size			
FOI7	Flow orifice, flashing, for	1/2" union, 1/8" D orifice	TC AMB1	Ambient air temperature, TC type T	20-150 F
SM18	Flow orifice, static mixer	1/2" union, 3/8" D orifice	TC FAN6	FAN6 motor housing temp, TC	100-300 F
SM19	Flow orifice, static mixer	1/2" union, 3/8" D orifice	SG B1	Test coupon wol1, bolt strain gage	0-6000 lb
SM20	Flow orifice, static mixer	1/2" union, 3/8" D orifice	SG B2	Test coupon wol2, bolt strain gage	0-6000 lb
FCV21	Flow control valve, pneumatic,	1/2" SS, swe	SG B3	Test coupon wol3, bolt strain gage	0-6000 lb
RV22	Pressure relief valve	1/2" mnpt X 1" fnpt, SS, 100 psig	SG B4	Test coupon wol4, bolt strain gage	0-6000 lb
CV23	Check valve, swing	1-1/2" SS, npt	CP S1	Test coupon wol1, corrosion	+/- 1000 mv
CV24	Check valve, swing	1/2" SS, swe	CP S2	Test coupon wol2, corrosion	+/- 1000 mv
FSC25	Strainer, replaceable screen	1/2" , socket weld, SS	CP S3	Test coupon wol3, corrosion	+/- 1000 mv
HV31	Main steam shutoff valve	1" gate valve, CS, npt	CP S4	Test coupon wol4, corrosion	+/- 1000 mv
HV32	Injection point shutoff valve	1/4" ball valve, SS, npt	CP-C5	Condensate corrosion potential	0-1 volts
HV33	Inlet valve for SCC2 chamber	1/2" gate, SS, swe	pH	Condensate pH	4-10 pH
HV41	Sample valve for CHEM5	1/4" ball valve, SS, npt	Cond	Condensate conductivity	0-2000 µs/cm
LS42	Level switch for PP8	Mechanical float switch			
OS43	Overflow switch for SUMP9	Mechanical float switch			

CRD Lab - History of Operation

1. Main Steam RTD	2. Chamber RTD
3. Calorimeter RTD	4. Chemistry Chamber RTD
5. Main Steam Pressure	6. Chamber Pressure
7. Calorimeter Pressure	8. Main Steam Flow

1. Coupon #1 TC	2. Coupon #2 TC
3. Coupon #3 TC	4. Coupon #4 TC
5. Strain Gage Coupon #1	6. Strain Gage Coupon #2
7. Strain Gage Coupon #3	8. Strain Gage Coupon #4

Chemistry Monitoring Channels - History of Operation

- 1. Corrosion Potential #1
- 2. Corrosion Potential #2
- 3. Corrosion Potential #3
- 4. Corrosion Potential #4
- 5. Corrosion Potential Condensate
- 6. Condensate pH
- 7. Condensate Conductivity

Lab Operating Parameters - Pressures - Sept. '99 - May '00

Lab Operating Parameters - Temperatures - Sept. '99 - May '00

Ambient & Sump Temp's - Sept99-May00

Well Head Chemistry

Well Head Chemistry Ammonia, Boron, Chloride Aug. '99 - May '00

Well Head Chemistry Non Condensable Gases (list #1) Aug. '99 - May '00

Well Head Chemistry Non Condensable Gases (list #2) Aug. '99 - May '00

Well Head Chemistry Non Condensable Gases Aug. '99 - May '00

pH & Bulk Temperature

Lab Chemistry Parameters - pH - Sept. '99 - May '00

Lab Chemistry Parameters - Bulk Condensate Corrosion Potential - Sept. '99 - May '00

Date & Time 9/29/99 5:57 10/16/99 5:58 11/1/99 11:16 11/18/99 6:21 12/3/99 11:24 12/26/99 3:07 2/17/00 7:07 3/11/00 2:17 4/8/00 3:26 4/24/00 8:29

Date & Time

Corrosion Potential
Switch Data Trend Feb. '00 - May '00

Lab Chemistry Parameters - Conductivity - Sept. '99 - May '00

Coupon Corrosion Potential Aug. '99 to May '00

Corrosion Potential
Switch Data Trend
Feb. '00 - May '00

Corrosion potential Data from PITS

Conductivity vs Temperature

WOL Temperatures - Sept. '99 - May '00

Strain Gage Output Sept. '99 - May '00

Strain Gage Output
Bolt #1 Sept' 99

Date & Time	9/10/99 7:16	9/12/99 9:33	9/19/99 6:21	9/21/99 8:38	9/23/99 10:55	9/25/99 1:11	9/27/99 3:28
Date & Time							

Strain Gage Output Bolt #2 Sept. '99

Strain Gage Output
Bolt #3 Sept. '99 - May '00

Date & Time 9/29/99 5:57 10/16/99 5:58 11/1/99 11:16 11/18/99 6:21 12/3/99 11:24 12/26/99 3:07 2/17/00 7:07 3/11/00 2:17

Date & Time

Strain Gage Output
Bolt #4 Sept. '99 - May '00

ATTACHMENT II-1
to
PREDICTING AND MITIGATING CRD IN GEOTHERMAL FACILITIES REPORT

SAMPLE AND TESTING DETAILS FOR DEVELOPMENT
OF THE
PITTING INITIATION DETECTION SYSTEM (PITS)
AND
EVENT ANALYSES /RESULTS LOGS
IN
CRD RESEARCH LABORATORY

Project # DOE-98-1

Prepared For:
U. S. DEPARTMENT OF ENERGY
(DE-FC07-98ID13656)

Prepared By:
Material Integrity Solutions, Inc.
Berkeley, CA
AUGUST, 2000

TEST #1

Pre Testing Condition:

SAMPLE A:

Solution:

Geysers steam condensate taken from the field lab. Initial pH after the addition of 2 drops of HCl and 1 drop of H₂SO₄ was approximately 4.0. On 4/14 solution was immersed in a heated bath and maintained at approximately 100°F. On 4/15, HCl was added to bring the pH down to 1.0 and temperature was maintained at 100°F. Solution maintained latter conditions for the remainder of the test.

Sample:

A stressed and unstressed electrode machined from rotor steel were placed in the single pair ceramic loading jig. The stressed electrode had the following initial and final loading:

Initial deflection and load: 0.030" ≈ 71ksi

Final deflection and load: 0.050" ≈ 119 ksi

Each electrode had a 20 AWG single strand teflon insulated wire soldered onto one end. This connection and the physical connections between the electrodes and the ceramic jigs were protected with a coating of silicon sealant.

SAMPLE B:

Solution:

Tap water with an initial pH of 6.5. On 4/9, .25 ml of HCl and H₂SO₄ were added to bring the pH down to 1.5. On 4/13 the pH was measured at 3 to 3.5. On 4/14 solution was immersed in a heated bath and maintained at approximately 100°F. On 4/15, HCl was added to bring the pH down to 1.0 and temperature was maintained at 100°F. On 4/16, HCl was again added to bring the pH down to 1.0 and actually ended up just below 1.0. Solution maintained latter conditions for the remainder of the test.

Sample:

A stressed and unstressed electrode machined from rotor steel were placed in the single pair ceramic loading jig. The stressed electrode had the following initial and final loading:

Initial deflection and load: 0.025" ≈ 61ksi

Final deflection and load: 0.0395" ≈ 96ksi

Each electrode had a 20 AWG single strand Teflon insulated wire soldered onto one end. This connection and the physical connections between the electrodes and the ceramic jigs were protected with a coating of silicon sealant.

Post Testing Conditions:

SAMPLE A:

Physical Condition of the Electrodes:

Unstressed Electrode:

Final Minimum Thickness 0.042" (net loss of 0.0205")

Final Minimum Width 0.350" (net loss of 0.025")

General Appearance: Exposed portion of electrode underwent uniform general corrosion with substantial loss of material on both sides. Both sides have a multitude of smallish pits uniformly distributed throughout the exposed surfaces.

Figure 1: Photograph of Test #1 Sample "A" Post-Test Condition.

Both sides saw a severe localized attack at the boundary of RTV sealant and metal. This attack was most severe at the attachment end, the erosion was $\frac{1}{2}$ the thickness of the electrode

Stressed Electrode:

Final Minimum Thickness 0.043" (net loss of 0.0195")

Final Minimum Width 0.352" (net loss of 0.023")

General Appearance: Exposed portion of electrode underwent uniform general corrosion with substantial loss of material on both sides. Both sides have a multitude of smallish pits uniformly distributed throughout the exposed surfaces.

Both sides saw a severe localized attack at the boundary of RTV sealant and metal. This attack was most severe at the attachment end, the erosion was $\frac{1}{3}$ the thickness of the electrode.

Figure 2. Photograph of Sample "A"'s Stressed Electrode Final Condition.

SAMPLE B:

Physical Condition of Electrodes:

Unstressed Electrode:

Final Minimum Thickness 0.059" (net loss of 0.0035")

Final Minimum Width 0.371" (net loss of 0.004")

General Appearance: Exposed portion of electrode underwent localized general corrosion. Both sides have a few distinct large and small pits distributed throughout the exposed surfaces.

Figure 3: Photograph of Test #1 Sample "B" Post-Test Condition.

Both sides saw a severe localized attack at the boundary of RTV sealant and metal. This attack was most severe at the attachment end, the erosion was $\frac{1}{2}$ the thickness of the electrode.

Stressed Electrode:

Final Minimum Thickness 0.058" (net loss of 0.0045")

Final Minimum Width 0.368" (net loss of 0.007")

General Appearance: Exposed portion of electrode underwent localized general corrosion. Both sides have a few distinct large and small pits distributed throughout the exposed surfaces.

Both sides saw a severe localized attack at the boundary of RTV sealant and metal. This attack was most severe at the attachment end, the erosion was $\frac{1}{2}$ the thickness of the electrode, which most likely accounted for the change in curvature of the electrode.

Figure 4: Photograph of Sample "B" Stressed & Unstressed Electrode- Final Condition

TEST #2

Pre Testing Condition:

Solution:

Tap water with a 2:1 ratio of HCl and H₂SO₄ added to bring the pH down to 1.0. On 6/30 the pH was measured at 3 to 3.5. Added HCl to bring the pH down to 1.0 and temperature was maintained at 100°F. On 7/1, HCl was again added to bring the pH down to about 1.0. Solution maintained latter conditions for the remainder of the test.

Sample:

Two stressed and two unstressed electrodes machined from rotor steel were placed in the dual pair ceramic loading jig. The stressed electrodes had the following initial and final loading:

Initial deflection and load: 0.025" $\approx$ 61ksi

Final deflection and load: not measured

Figure 5: Photograph of Loading Jig and Electrodes Prior to Test.

Each electrode had a 20 AWG single strand Teflon insulated wire soldered onto one end. This connection and the physical connections between the electrodes and the ceramic jigs were protected with a combination of enamel and silicon sealant. Figure 12 shows this arrangement.

Post Testing Conditions:

Physical Condition of Electrodes:

Corrosion was very severe as all electrodes exhibited heavy pitting and loss of material. There was little to no evidence of an oxide layer upon removing the samples from the solution. The metal was blackened and the surfaces were rough with black metal flakes. Figure 13 shows the final condition of the electrode assembly.

Figure 6: Photograph of Post-Test Condition of Electrodes.

The 'pits' ranged in size from $1/32''$ to $1/64''$ in diameter. No major crevice corrosion was apparent. The stressed samples had lost enough material that they were beginning to yield.

TEST #3

Solution:

Geysers steam condensate taken from the Lab with pH of 4.0. Six 'pinches' NaCl were added and dissolved in the solution to provide greater likelihood of pitting corrosion. Solution was immersed in a heated bath and maintained at approximately 100°F for the duration of the test.

Sample:

There was a voltage/current assembly consisting of a common stressed 'working' electrode, two unstressed electrodes (one for voltage, one for current), and noble wire corrosion potential probe. Figure 18 shows the electrode arrangement in solution. The stressed electrode was simply a bent metal electrode such that residual stresses would provide the constant stressed condition required for the test. The other assembly consisted of two unstressed electrodes for current measurement. All electrodes were manufactured from rotor steel.

Figure 7: Close-up Photograph of Test #3 Electrode Arrangement.

Physical Conditions of Electrodes:

All electrodes exhibited general corrosion and an oxide layer. Metallographic examination revealed surface micro-cracks and some pitting as shown in Figures 19 and 20 below.

7-22-99 Silver lead, top
12.5x 810.000 160.000

Figure 8: Photo-micrograph of Electrode Surface Condition – Note Surface Cracks and Pits.

7-22-99 Silver lead, bottom
12.5x 810.000 160.000

Figure 9: Photo-micrograph of Electrode Surface Condition – Note Large Pit.

EVENT VIEWING/ANALYSES BY DADISPTM SOFTWARE

AND

PITTING EVENT TABLES AND CHARTS

Manuchehr Shir

From: "Morgan, Bryan C" <BXM0@pge.com>
To: "Manuchehr Shirmohamadi - MIS" <mshir@MISolution.com>
Sent: Friday, April 28, 2000 10:34 AM
Subject: CP Data

Manuchehr:

I know you wanted to try and close out your CP project by the end of the month, so I thought I would try to get this additional signal analysis to you ASAP. If you want a further explain we can still meet next Wednesday, if not that is fine too. Consider the next Wednesday meeting gratis on my part.

Thanks

Bryan Morgan

Conclusions:

Attached is a set of bitmaps showing the correlation between moving average of CP2 and I2 spikes, and between moving average of CP1 and I2 spikes. I looked at the same 9 days in March as before. It is possible, but not conclusive to say that the potential moving average was related to the degree of corrosive environment. Specific conclusions are:

1- A moving average window of 1 minute was sufficient for CP2 data to eliminate the one time-step pulses and show trends. A moving average window of 5 minutes for CP1 data was ideal, but it could be as low as 1 minute.

2- Spikes in the I2 data occurred when the CP2 moving average was greater than -0.075 millivolts (volts ?) threshold. No spikes occurred with a more negative value. However just because the moving average was higher than the threshold did not mean that spikes would occur. The last three days evaluated had no spikes, but the moving average exceeded the threshold. [Note, this may be a case of the switch's sensitivity decaying toward the end of the test.]

3- There was little variation in the CP1 data level. Its moving average did not appear to be related in any way to the I2 spikes.

4- Ignoring the I2 spikes, there appear to be occurrences when the I2 and CP2 signal levels trend together. Specifically this can be seen on the sw031100-8 bitmap for dips at 21000 and 35000 seconds. I can think of two possible reasons, (1) the trend may be related to common signal amplification electronics or (2) it is an indication of the steam corrosion potential.

Generally the bitmaps cover the entire 24 hour period (86,400 seconds). The highpass is >0.2 Hz. The lowpass is < 0.2 Hz. [Note, I used these frequencies to clarify the spikes, but it may decrease their amplitude somewhat.] All moving averages are 1 minute windows unless otherwise noted.

Spikes occur at:

Bitmap Data Comparison Approximate time of spikes (in seconds)
 sw031100-8 CP2 vs I2 13000, 27000, 71000, & 86000

8/28/00

sw031100-9 CP1 vs I2 same
(5 min. window)
sw031100-10 CP1 vs I2 same

sw031500-2 CP2 vs I2 2400, 30500 (positive spike)
sw031500-3 CP1 vs I2 same

sw031600-7 CP2 vs I2 12000, 12500, 19000, 19500, 49000,
70800
sw031600-8 CP1 vs I2 same

sw031700-1 CP2 vs I2 no spikes
sw031700-2 CP1 vs I2 no spikes

sw032000-4 CP2 vs I2 1000, 4000, 7500, 9500, 12000,
14500, 17000, 18000, 20500, 30000, 33000,
37000, 44000, 47000, 52000, 56000,
59000, 64000, 75000, 83000.
sw032000-5 CP1 vs I2 same

sw032100-3 CP2 vs I2 2000, 5200, 5400, 5600, 5700, 10500,
12000, 14000, 17000, 24500, 26500,
29000, 31500, 33000, 34500, 37000,
38500.
sw032100-4 CP1 vs I2 same

sw032500-1 CP2 vs I2 no spikes
sw032500-2 CP1 vs I2 no spikes

sw032900-1 CP2 vs I2 no spikes
sw032900-2 CP1 vs I2 no spikes

sw040100-2 CP2 vs I2 no spikes
sw040100-3 CP1 vs I2 no spikes

MIS SWITCH DATA FOR 2/01/2000 THROUGH 4/01/2000

- Notes: [1] - Very small spikes in V1, V2, and Ref. Taking differential eliminates them completely
 [2] - Short duration spikes typically 1-2 TS < 2, of less than .01 milliamps, and no increase in PSD near 0 Hz.
 [3] - Bad data, appears to be a very low level bang-bang. Figure sw020399-1 is an example.
 [4] - Highpass filter is > 0.6 Hz, lowpass filter is < 0.6 Hz. Only lowpass filter is used in gated signal and spectra
 Could use lowpass filter < 0.2 Hz to filter out noise, then threshold on amplitude.

MIS File	Dadisp File	time	CP1	CP2	I1	I2	V1 - Ref.	V2 - Ref.
sw020399	sw020399.1	0-4 hrs.	[3]	[3]	[3]	[3]	bad data	[1]
	sw020399.2	4-8 hrs.	[3]	[3]	[3]	[3]	bad data	[1]
	sw020399.3	8-12 hrs.	[3]	[3]	[3]	[3]	bad data	[1]
	sw020399.4	12-16 hrs.	[3]	[3]	[3]	[3]	bad data	[1]
	sw020399.5	16-20 hrs.	[3]	[3]	[3]	[3]	bad data	[1]
	sw030399.6	20-24 hrs.	[3]	[3]	[3]	[3]	bad data	[1]
sw020999	sw030999.1	0-4 hrs.	[3]	[3]	[3]	[3]	[1] & few [2]	[1] & few [2]
	sw030999.2	4-8 hrs.	[3]	[3]	[3]	[3]	[1] & few [2] partly bad data	[1] & few [2]
	sw030999.3	8-12 hrs.	[3]	[3]	[3]	[3]	bad data	[1] & few [2]
	sw030999.4	12-16 hrs.	[3]	[3]	[3]	[3]	[1] & few [2] partly bad data	[1] & few [2]
	sw030999.5	16-20 hrs.	[3]	[3]	[3]	[3]	[1] & few [2] partly bad data	[1]
	sw030999.6	20-24 hrs.	[3]	[3]	[3]	[3]	[1] & few [2] partly bad data	[1]
sw021799	sw021799.1	0-4 hrs.	[3]	[3]	[3]	[3]	[1]	[1]
	sw021799.2	4-8 hrs.	[3]	[3]	[3]	[3]	[1]	[1]
	sw021799.3	8-12 hrs.	[3]	[3]	[3]	[3]	[1]	[1] & few [2]
	sw021799.4	12-16 hrs.	[3]	[3]	[3]	[3]	[1]	[1]
	sw021799.5	16-20 hrs.	[3]	[3]	[3]	[3]	[1]	[1]
	sw021799.6	20-24 hrs.	[3]	[3]	[3]	[3]	[1]	[1]
sw031100	sw031100.1	0-4 hrs.	no	many 1 TS spikes, .01 millivolt, Fig. Sw031100-1	no	1 spike, .01 milliamp, 50 sec, fig. Sw031100-2	[1] & 12 [2] fig. Sw031100-6	[1] & many [2] fig. Sw031100-7
	sw031100.2	4-8 hrs.	no	many 1 TS spikes, .01 millivolt	no	1 spike, .01 milliamp, 30 sec, fig. Sw031100-2	[1] & many [2] - partly bad data	[1] & many [2]
	sw031100.3	8-12 hrs.	no	many 1 TS spikes, .05 millivolt	no	no	bad data	[1] & many [2]
	sw031100.4	12-16 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	bad data	[1] & many [2]
	sw031100.5	16-20 hrs.	no	no	no	1 spike, .008 milliamp, 30-50 sec, fig sw031100-4	bad data	[1] & many [2]
	sw031100.6	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	1 spike, .012 milliamp, 40 sec, fig sw031100-5	[1] & many [2]	[1] & many [2]
sw031500	sw031500.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	1 spike, .005 milliamp, 30 sec like fig sw031100-5	[1]	[1]
	sw031500.2	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	bad data	[1] & few [2]
	sw031500.3	8-12 hrs.	no	no	no	1 spike, .01 milliamp, 20 sec fig sw031500-1	bad data	[1] & few [2]
	no more data files for sw031500							
sw031600	sw031600.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	2 spikes, +.005 milliamp, 30 sec fig sw031600-1, & -.006 milliamp, 30 sec fig sw031600-2	2 spikes, .08 milliamp, 30 sec fig sw031600-3 (same time as sw031600-1 spike), & .05 milliamp 60 sec fig sw031600-4	bad data	[1] & few [2]
	sw031600.2	4-8 hrs.	no	no	no	2 small spikes, .04 milliamp, 20 sec similar to fig sw031600-3	bad data	[1] & few [2]
	sw031600.3	8-12 hrs.	no	a few 1 TS spikes, .05 millivolt	1 spike, .007 milliamp, 200 sec fig sw031600-5	no	bad data	[1] & few [2]
	sw031600.4	12-16 hrs.	no	no	no	1 spike, .06 milliamp, 40 sec similar to fig sw031600-3	[1] & some [2] - partly bad data	[1] & few [2]
	sw031600.5	16-20 hrs.	no	a few 1 TS spikes, .05 millivolt	no	1 spike, .06 milliamp, 40 sec similar to fig sw031600-3	[1] & few [2]	[1] & few [2]
	sw031600.6	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1] & few [2]	[1] & few [2]
sw031700	sw031700.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]	[1] - partly bad data

sw031700.2	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1] - partly bad data	[1] - partly bad data
sw031700.3	8-12 hrs.	no	no	no	no	[1]	[1]
sw031700.4	12-16 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]	[1] & few [2]
sw031700.5	16-20 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]	[1] & few [2]
sw031700.6	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]	[1] & few [2]
sw032000	sw032000.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	8 spikes, .005-.008 milliamps, 20- 60 sec fig sw032000-1, & 2 are examples	[1] fig sw032000-3
	sw032000.2	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	4 spikes, .005 milliamps, 40-60 sec like sw032000-1, & 2	[1]
	sw032000.3	8-12 hrs.	no	a few 1 TS spikes, .05 millivolt	no	4 spikes, .005 milliamps, 40-60 sec like sw032000-1, & 2	[1]
	sw032000.4	12-16 hrs.	no	a few 1 TS spikes, .05 millivolt	no	4 spikes, .005 milliamps, 40-60 sec like sw032000-1, & 2	[1]
	sw032000.5	16-20 hrs.	no	a few 1 TS spikes, .05 millivolt	no	3 spikes, .005 milliamps, 40-60 sec like sw032000-1, & 2	[1]
	sw032000.6	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	4 spikes, .005 milliamps, 40-60 sec like sw032000-1, & 2	[1]
sw032100	sw032100.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	8 spikes, .005 milliamps, 20-60 sec fig sw032100-1	[1]
	sw032100.2	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	3 spikes, .005 milliamps, 40-60 sec fig sw032100-2	[1]
	sw032100.3	8-12 hrs.	no	a few 1 TS spikes, .05 millivolt	no	6 spikes, .004 milliamps, 20-40 sec fig sw032100-2	[1]
no more data files for sw032100							
sw032500	sw032500.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032500.1	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032500.1	8-12 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032500.1	12-16 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032500.1	16-20 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032500.1	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
sw032900	sw032900.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032900.2	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032900.3	8-12 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032900.4	12-16 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032900.5	16-20 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw032900.6	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
sw040100	sw040100.1	0-4 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw040100.2	4-8 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw040100.3	8-12 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no (raw waveform has a more negative value than for earlier files with spikes) fig sw040100-1	[1]
	sw040100.4	12-16 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw040100.5	16-20 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]
	sw040100.6	20-24 hrs.	no	a few 1 TS spikes, .05 millivolt	no	no	[1]

Conclusions:

- [1] V1, V2 and Ref channels had same spikes in them. This is demonstrated by their differential plots (V1-Ref, and V2-Ref.)
- [2] CPS has many 1 time (1 TS) pulses. There is no trailing edge to signal.
- [3] No indication of corrosion like signals on Channels CP1, CP2, V1-Ref, V2-Ref were found.
- [4] I2 has corrosion like signals typically .005 milliamps and 20-60 seconds. This small of signal has very little effect on PSD. The signal amplitude would appear to decrease with test duration, starting with .01 milliamp and decreasing to .004 milliamps. Later data files had no I2 corrosion like signals. Average rate appears to be 1 per hour.
- [5] I1 has some corrosion like signals for a small period of test duration. Their Incident times do not match the I2 signal occurrence times.

W8: Sw032000.4, Time

W9: Sw032000.4, I2

W10: xyinterp(W8,W9,25)setkoffset(0.0)

W4: Signal Envelope(W2)

W5: Threshold Crossings(W4)

W3: Spectrum(W2)setxlog(Y)setx(0.000,2)

W12: HighPass Filter Signal(W1)

W13: LowPass Filter Signal(W1)

W14: Gated Signal(W13)

W2: Analysis Signal(W14)

W7: Signal above Threshold(W2)

W6: Power Spectrum Partial Powers(W2)

W11: Spectrum vs Time (W2)

W10: Log of Power Spectral Density(W2)

Spikes

- Dips in CPZ & IZ ,
even though they are
on different swiches.

- Spikes when $IZ > -0.75$
 CPZ .

- (min window CPZ

5 min window CPZ

SW031100-8 (CPZ)
(24 hr period)
High Pass $> 0.2 Hz$
Low Pass $< 0.2 Hz$.

date+time	Pitting Charge	Q. P2P	Acc. Charge	Rate
2/2/00 12:00 AM			0	
2/4/00 11:13 AM	0.0110932	0.000194	0.0110932	
2/4/00 1:12 PM	0.353729	0.010000	0.3648222	4.27144
2/6/00 11:22 AM	0.0393769	0.000579	0.04041991	0.02047
2/6/00 9:21 PM	0.157704	0.012309	0.5619031	0.37903
2/8/00 1:17 PM	0.00739481	0.000130	0.56929791	0.00445
2/11/00 9:29 AM	0.181136	0.002135	0.75043391	0.06375
2/12/00 1:48 PM	0.124128	0.001561	0.87456191	0.10517
2/12/00 4:11 PM	0.0847948	0.011025	0.95935671	0.85388
2/14/00 3:14 PM	0.0336515	0.000486	0.99300821	0.01717
2/19/00 11:33 AM	1.52858	0.010635	2.52158821	0.31539
2/19/00 11:41 AM	1.98181	0.037087	4.50339821	358.21838
2/19/00 11:42 AM	2.22374	0.026732	6.727113821	4087.89648
2/19/00 1:38 PM	0.0765965	0.020359	6.80373471	0.95277
2/28/00 8:44 PM	1.51608	0.010000	8.31981471	0.16309
2/28/00 8:45 PM	0.725561	0.005832	9.04537571	824.84829
3/13/00 8:26 AM	0.0602445	0.001013	9.10562021	0.00447
3/13/00 8:27 AM	0.694622	0.003360	9.80024221	983.85804
3/13/00 8:31 AM	0.173243	0.002857	9.97348521	59.39760
3/14/00 11:47 AM	0.37519	0.004280	10.34867521	0.33023
3/14/00 3:52 PM	0.0564582	0.002440	10.40513341	0.33213
3/14/00 5:11 PM	0.0556547	0.001706	10.46078811	1.01920
3/15/00 1:35 AM	0.31243	0.003360	10.77321811	0.89133
3/15/00 3:57 AM	0.0573061	0.002011	10.83052421	0.58175
3/15/00 7:21 PM	0.523009	0.014650	11.35353321	0.81531
3/15/00 7:22 PM	0.207984	0.005710	11.56151721	289.83577
3/15/00 7:24 PM	0.652793	0.009470	12.21431021	648.29098
3/15/00 7:37 PM	0.241969	0.003050	12.45627921	24.97745
3/16/00 12:32 PM	0.0585018	0.001587	12.51478101	0.08306
3/16/00 9:01 PM	0.168075	0.005759	12.68285601	0.47508
3/16/00 9:04 PM	0.0581741	0.003435	12.74103011	27.02281
3/17/00 6:32 AM	0.0570286	0.001896	12.79805871	0.14453
3/17/00 8:54 AM	0.145818	0.002894	12.94387671	1.47889
3/18/00 3:16 PM	0.293589	0.002750	13.23746571	0.23204
3/19/00 7:44 AM	0.748373	0.003360	13.98583871	1.09176
3/22/00 9:57 AM	0.0997628	0.003050	14.08560151	0.03226
3/22/00 7:41 PM	0.174727	0.002750	14.26032851	0.43054
3/26/00 10:44 PM	0.558358	0.011600	14.81866651	0.13530
3/26/00 10:45 PM	0.711208	0.016480	15.52889451	660.73518
4/4/00 1:42 AM	0.617993	0.008240	16.14788751	0.07608
4/4/00 1:21 PM	0.465472	0.021372	16.61335951	0.95777
4/4/00 1:22 PM	0.558808	0.025968	17.17216751	910.96248
4/4/00 1:28 PM	0.774337	0.028743	17.94650451	186.87910
4/4/00 1:30 PM	2.21419	0.038696	20.16069451	1708.08943
4/4/00 4:09 PM	1.05208	0.012520	21.21277451	9.54929
4/4/00 4:21 PM	0.584731	0.011900	21.79750551	70.55972
4/4/00 4:42 PM	1.2064	0.014382	23.00390551	80.86343
4/4/00 7:28 PM	0.177698	0.008234	23.18160351	1.54132
4/4/00 9:42 PM	0.284345	0.011290	23.47594851	3.17535
4/4/00 9:50 PM	1.27562	0.013420	24.75156851	218.24469
4/5/00 9:21 PM	0.67722	0.013740	25.42878851	0.69131
4/5/00 10:24 PM	2.03456	0.018620	27.46334851	46.18654
4/12/00 7:20 AM	0.314632	0.006727	27.77798051	0.04938
4/15/00 9:08 PM	0.120768	0.005490	27.89874851	0.03378
4/17/00 9:09 PM	0.0902394	0.003547	27.98898791	0.04511
4/21/00 3:18 PM	0.146662	0.004367	28.13564991	0.03904
4/21/00 3:19 PM	0.122296	0.004570	28.25794591	211.32749
4/21/00 8:08 PM	0.123785	0.006604	28.38173091	0.61653
4/21/00 11:37 PM	0.120412	0.006410	28.50214291	0.82831
4/22/00 7:27 AM	0.146052	0.006202	28.64819491	0.44742
4/23/00 9:02 PM	0.160072	0.004379	28.80826691	0.10221
4/23/00 10:07 PM	0.106614	0.006264	28.91488091	2.36252
4/24/00 6:49 AM	0.130073	0.004708	29.04495391	0.35897
4/27/00 5:22 PM	0.124563	0.009770	29.16951691	0.03621
4/27/00 8:03 PM	0.563421	0.008914	29.73293791	5.05604
4/30/00 4:51 AM	0.0731545	0.003861	29.80609241	0.03091
5/1/00 6:06 PM	0.0780772	0.002781	29.88416961	0.05029
5/1/00 10:23 PM	1.11979	0.008087	31.00395961	6.28858
5/2/00 8:58 AM	0.112043	0.003661	31.11600261	0.25384
5/3/00 8:43 PM	0.0652356	0.003580	31.18123821	0.04380
5/4/00 4:22 AM	0.0681279	0.003438	31.24936611	0.21384
5/5/00 9:37 PM	0.155434	0.005800	31.40480011	0.09043
5/6/00 8:11 AM	0.255694	0.005190	31.66049411	0.58114
5/6/00 6:09 AM	0.0642887	0.002997	31.72478281	0.03356
5/10/00 3:44 AM	0.0821882	0.004270	31.80697101	0.04327
5/11/00 1:21 AM	0.188044	0.004577	31.99501501	0.20881
5/11/00 1:31 AM	0.0767102	0.003172	32.07172521	10.91888
5/11/00 2:04 AM	0.101129	0.003372	32.17285421	4.46021
5/11/00 2:04 AM	0.0287059	0.002815	32.20156011	72.94676
5/11/00 3:11 AM	0.174852	0.012480	32.37641211	3.79102
5/11/00 3:11 AM	0.491182	0.014611	32.86759411	1515.64730
5/11/00 3:14 AM	0.156623	0.016104	33.02421711	94.63096
5/11/00 3:15 AM	0.0894529	0.018220	33.11367001	92.00870
5/11/00 3:15 AM	0.28692	0.020014	33.40059001	1180.47086
5/11/00 3:16 AM	0.252367	0.021504	33.65295701	411.40582
5/11/00 3:17 AM	0.200902	0.022676	33.85385901	559.93332
5/11/00 3:20 AM	1.68122	0.034598	35.53507901	691.70194
5/11/00 3:21 AM	0.969988	0.034898	36.50506701	2618.96761
5/11/00 3:22 AM	1.08988	0.040122	37.60404701	912.98877
5/11/00 3:25 AM	1.14931	0.052331	38.75335701	746.61943
5/11/00 3:25 AM	0.342348	0.045219	39.09570501	1095.51360
5/11/00 3:28 AM	2.27188	0.055100	41.36758501	1226.81520
5/11/00 5:25 AM	0.134525	0.045826	41.50211001	1.65499
5/11/00 6:26 AM	0.146596	0.035826	41.64870601	3.45874
5/11/00 6:27 AM	0.291743	0.035513	41.94044901	572.87716
5/11/00 6:33 AM	0.243238	0.035310	42.18368701	56.34253

Test Date	7/1/99 12:00A	8/1/99 0:00	10/1/99 0:00	11/1/99 0:00	12/1/99 0:00	2/1/00 0:00	2/16/00 0:00	3/2/00 0:00	4/11/00 0:00	5/11/00 0:00
Water Vapor	999000	998000	997000	994000	997000	999000	999000	999000	1000000	1000000
Carbon Dioxide	12.7	21.1	26.1	53.6	28	6.39	11	3.62	2.73	3.72
Hydrogen Sulfide	7.90	10.20	11.70	9.54	5.96	3.69	6.10	2.43	2.09	2.15
Ammonia	18.50	20.60	22.30	13.80	7.95	13.30	16.70	18.30	7.34	10.70
Argon	0.171	0.142	0.0997	0.195	0.0683	1.39	0.819	1.22	0.849	0.556
Nitrogen	2.64	5.30	4.92	1.13	5.35	6.50	5.36	5.25	3.32	2.41
Methane	6.03	10.60	12.10	28.50	13.50	6.64	7.90	3.84	1.26	1.60
Hydrogen Fluoride	1.09	1.61	1.76	7.04	6.33	1.44	1.23	0.88	0.50	0.52
Chloride	3.70	5.40	0.98	0.98	0.47	5.98	2.70	4.54	4.66	7.22
Boron	35.00	51.20	32.80	14.60	11.90	na	33.60	50.10	40.20	49.10
Time	Hydrogen Sulfide	Ammonia	Argon	Nitrogen	Methane	Hydrogen Fluoride	Chloride	Boron		
8/1/99 0:00	7.90	18.50	0.171	2.64	6.03	1.09	3.70	35.00		
8/1/99 0:00	10.20	20.60	0.142	5.30	10.60	1.61	5.40	51.20		
10/1/99 0:00	11.70	22.30	0.0997	4.92	12.10	1.76	0.98	32.80		
11/1/99 0:00	9.54	13.80	0.195	1.13	28.50	7.04	0.98	14.60		
12/1/99 0:00	5.96	7.95	0.0683	5.35	13.50	6.33	0.47	11.90		
2/1/00 0:00	3.69	13.30	1.39	6.50	6.64	1.44	5.98	na		
2/16/00 0:00	6.10	16.70	0.819	5.36	7.90	1.23	2.70	33.60		
3/2/00 0:00	2.43	18.30	1.22	5.25	3.84	0.88	4.54	50.10		
4/11/00 0:00	2.09	7.34	0.849	3.32	1.26	0.50	4.66	40.20		
5/11/00 0:00	2.15	10.70	0.556	2.41	1.60	0.52	7.22	49.10		

5/11/00 8:23 AM	2.90538	0.035244	45.08906701	38.09756
5/11/00 8:30 AM	0.397378	0.034173	45.48644501	73.99452
5/11/00 8:38 AM	0.654643	0.033372	46.14108801	120.85717
5/11/00 9:04 AM	0.163703	0.032154	46.30479101	9.04923
5/11/00 9:32 AM	0.351056	0.032221	46.65584701	18.12985
5/11/00 9:39 AM	0.265707	0.030839	46.92155401	57.53655
5/13/00 7:49 PM	0.125422	0.005229	47.04697601	0.05174
5/17/00 3:48 AM	2.26373	0.061361	49.31670601	0.68110
5/18/00 7:39 AM	0.0942538	0.002740	49.41095981	0.08123
5/18/00 8:08 AM	0.0691665	0.003670	49.48012631	3.40318
5/18/00 8:20 AM	0.0658297	0.002384	49.54595601	7.86679
5/18/00 7:34 PM	1.07666	0.066851	50.62261601	2.30319
5/19/00 2:45 AM	4.04134	0.067001	54.66395601	13.47737
5/19/00 2:48 AM	0.383447	0.065238	55.04740301	204.50507
5/19/00 10:47 AM	0.0602628	0.002440	55.10766581	0.18102
5/19/00 12:12 PM	0.0703533	0.003970	55.17801911	1.20224
5/19/00 4:12 PM	0.0809654	0.003357	55.25898451	0.48627
5/19/00 6:14 PM	0.0975425	0.003360	55.35652701	1.14897
5/19/00 6:26 PM	0.117916	0.001633	55.47444301	13.74891
5/19/00 6:40 PM	0.123608	0.002097	55.59805101	12.49091
5/19/00 6:52 PM	0.0755074	0.003970	55.67355841	9.12425
5/19/00 6:54 PM	0.145302	0.004880	55.81886041	110.12362
5/19/00 6:58 PM	1.08022	0.006410	56.89908041	392.14709
5/19/00 7:36 PM	0.175464	0.004270	57.07454441	6.71692
5/19/00 11:01 PM	0.0752132	0.001520	57.14975761	0.52653
5/19/00 11:06 PM	0.207299	0.006410	57.35705661	62.84433
5/20/00 3:11 AM	0.299474	0.006410	57.65653061	1.76341
5/20/00 3:39 AM	0.0787673	0.003050	57.73529791	3.95898
5/20/00 8:37 AM	0.0984974	0.004890	57.83379531	0.47612
5/20/00 4:58 PM	1.69583	bad data	59.52962531	4.88204
5/20/00 7:23 PM	0.489771	bad data	60.01939631	4.86393
5/20/00 7:52 PM	0.98308	bad data	61.00247631	47.45146
5/21/00 5:40 AM	2.86083	bad data	63.86330631	7.00810
5/21/00 9:18 AM	1.9969	bad data	65.66020631	13.21073
5/21/00 9:22 AM	1.44389	bad data	67.30409631	533.12862
5/21/00 11:53 AM	0.371418	0.006720	67.67551431	3.53576
5/21/00 3:09 PM	0.126435	0.004880	67.80194931	0.93137
5/21/00 3:35 PM	0.0824886	0.002181	67.88443791	4.46275
5/21/00 4:01 PM	1.11381	0.005500	68.99824791	61.49085
5/21/00 5:11 PM	0.0649477	0.003050	69.06319561	1.34278
5/21/00 5:31 PM	0.12069	0.004890	69.18388561	8.45711
5/21/00 8:49 PM	0.126837	0.005500	69.31072261	0.92206
5/21/00 8:51 PM	0.0630807	0.003050	69.37380331	53.43306
5/22/00 12:10 AM	0.150589	0.003670	69.52439231	1.09143
5/22/00 4:25 AM	0.100848	0.002671	69.62524031	0.56942
5/22/00 7:40 AM	0.0926299	0.003184	69.71787021	0.68258
5/22/00 7:52 AM	0.596622	0.006100	70.31449221	75.14306
5/22/00 7:55 AM	0.846978	0.005800	71.16147021	397.71141
5/22/00 8:09 AM	0.211697	0.006410	71.37316721	22.27847
5/22/00 8:22 AM	0.305384	0.006110	71.67855121	33.56893
5/22/00 8:35 AM	0.180264	0.002490	71.85981521	19.27575
5/22/00 8:49 AM	0.114598	0.003360	71.97341321	11.88628
5/22/00 9:02 AM	0.132389	0.002750	72.10580221	14.12149
5/22/00 9:16 AM	0.150889	0.003970	72.25569121	16.31641
5/22/00 9:33 AM	1.17209	0.005800	73.42878121	96.81508
5/22/00 9:48 AM	0.0892566	0.002204	73.51803781	8.86410
5/22/00 9:57 AM	0.238378	0.004880	73.75641581	39.00731
5/23/00 4:12 PM	0.129524	0.002025	73.88593981	0.10275
5/23/00 4:56 PM	0.164578	0.004338	74.05051781	5.38415
5/23/00 5:08 PM	0.321146	0.006410	74.37166381	37.80247
5/23/00 5:09 PM	0.0963306	0.003970	74.46799441	104.03705
5/23/00 5:55 PM	0.0888394	0.005190	74.55683381	2.82611
5/23/00 6:32 PM	0.101525	0.003970	74.65835881	3.96195
5/23/00 7:53 PM	0.0794052	0.004580	74.73776401	1.40962
5/24/00 1:23 AM	0.0554259	0.003328	74.79318991	0.24179
5/24/00 4:55 AM	0.474892	0.006110	75.26808191	3.21532
5/24/00 6:13 AM	0.0504551	0.002590	75.31853701	0.94073
5/24/00 8:30 PM	0.0508571	0.003360	75.36939411	0.08544
5/26/00 3:27 PM	0.0827789	0.003970	75.45217301	0.04626
5/26/00 6:31 PM	0.0639331	0.002440	75.51610611	0.49913
5/26/00 6:46 PM	0.0698789	0.001830	75.58598501	6.93173
5/30/00 4:12 PM	0.0974216	0.003970	75.68340661	0.02502
5/30/00 4:37 PM	0.0497293	0.002130	75.73313591	2.91889
5/30/00 7:12 PM	0.0623801	0.003360	75.79551601	0.57891
5/30/00 7:49 PM	0.0533309	0.002440	75.84884691	2.07185
5/30/00 9:26 PM	0.164772	0.004890	76.01361891	2.44274
5/30/00 9:44 PM	0.156266	0.004880	76.16988491	12.87072
5/30/00 10:27 PM	0.10179	0.004580	76.27167491	3.43139
5/30/00 10:59 PM	0.665419	0.005180	76.93709391	29.51345
5/31/00 12:37 AM	0.0590473	0.003603	76.99614121	0.87015
5/31/00 12:43 AM	0.0920624	0.003360	77.08820361	20.50049
5/31/00 12:57 AM	0.0589184	0.001353	77.14712201	6.18536
5/31/00 1:12 AM	0.4961	0.005800	77.64322201	46.59026
5/31/00 7:19 AM	0.069094	0.002228	77.73231601	0.35012
5/31/00 8:38 AM	0.0596534	0.004270	77.79186941	1.07758
5/31/00 8:47 AM	0.0544638	0.001401	77.84643321	9.03200

4.04134
0.00739481
0.430090791
0.62863865

Event	Date	Time	Duration	Area	Energy	Max	Min	Peak2Peak	date+time	ting Chan	Q. E	Q. P2P
1	2/4/99	11:13:34	167.75	0.0111	0.0000	0.0002	0.0000	0.000194	2/4/99 11:13	0.01109	1.828E-06	0.000194
2	2/4/99	13:12:49	17.24	0.3537	0.0022	0.0000	-0.0100	0.01	2/4/99 13:12	0.35373	0.002155	0.01
3	2/6/99	11:22:30	172.24	0.0394	0.0000	0.0006	0.0000	0.000579	2/6/99 11:22	0.03938	1.854E-05	0.000579
4	2/6/99	21:21:39	34.50	0.1577	0.0005	0.0023	-0.0100	0.012309	2/6/99 21:21	0.1577	0.0004716	0.012309
5	2/8/99	13:17:11	167.76	0.0074	0.0000	0.0001	0.0000	0.00013	2/8/99 13:17	0.00739	8.125E-07	0.00013
6	2/11/99	9:29:00	181.26	0.1811	0.0003	0.0021	0.0000	0.002135	2/11/99 9:29	0.18114	0.0002896	0.002135
7	2/12/99	13:48:32	178.00	0.1241	0.0001	0.0016	0.0000	0.001561	2/12/99 13:48	0.12413	0.0001494	0.001561
8	2/12/99	16:11:32	116.25	0.0848	0.0002	0.0010	-0.0100	0.011025	2/12/99 16:11	0.08479	0.0001611	0.011025
9	2/14/99	15:14:34	172.75	0.0337	0.0000	0.0005	0.0000	0.000486	2/14/99 15:14	0.03365	1.325E-05	0.000486
10	2/17/99	11:13:09	167.51	9.1928	0.1450	0.0107	-0.0200	0.030705	2/17/99 11:13	bad data	0.144963	0.030705
11	2/19/99	11:33:44	211.01	1.5286	0.0108	0.0106	0.0000	0.010635	2/19/99 11:33	1.52858	0.0108491	0.010635
12	2/19/99	11:41:42	46.74	1.9818	0.0245	-0.0029	-0.0400	0.037087	2/19/99 11:41	1.98181	0.0245113	0.037087
13	2/19/99	11:42:29	42.99	2.2237	0.0369	-0.0033	-0.0300	0.026732	2/19/99 11:42	2.22374	0.0368804	0.026732
14	2/19/99	11:43:12	172.00	6.4325	0.0622	0.0063	-0.0100	0.016323	2/19/99 11:43	bad data	0.0622332	0.016323
15	2/19/99	13:38:15	21.99	0.0766	0.0007	0.0004	-0.0200	0.020359	2/19/99 13:38	0.0766	0.0007097	0.020359
16	2/19/99	13:43:20	157.75	10.2253	0.1970	-0.0012	-0.0300	0.028799	2/19/99 13:43	bad data	0.19699	0.028799
17	2/28/99	20:44:21	70.24	1.5161	0.0113	0.0000	-0.0100	0.01	2/28/99 20:44	1.51608	0.011276	0.01
18	2/28/99	20:45:37	201.24	0.7256	0.0029	0.0058	0.0000	0.005832	2/28/99 20:45	0.72556	0.0028794	0.005832
19	3/13/00	8:26:30	24.25	0.0602	0.0000	-0.0002	-0.0012	0.001013	3/13/00 8:26	0.06024	4.145E-05	0.001013
20	3/13/00	8:27:31	167.76	0.6946	0.0008	0.0006	-0.0028	0.00336	3/13/00 8:27	0.69462	0.0008365	0.00336
21	3/13/00	8:31:43	42.48	0.1732	0.0003	-0.0002	-0.0031	0.002857	3/13/00 8:31	0.17324	0.0002515	0.002857
22	3/14/00	11:47:47	60.75	0.3752	0.0008	0.0003	-0.0040	0.00428	3/14/00 11:47	0.37519	0.0007557	0.00428
23	3/14/00	15:52:34	27.25	0.0565	0.0000	0.0012	-0.0012	0.00244	3/14/00 15:52	0.05646	3.524E-05	0.00244
24	3/14/00	17:11:12	22.24	0.0557	0.0000	0.0018	0.0001	0.001706	3/14/00 17:11	0.05565	3.962E-05	0.001706
25	3/15/00	1:35:57	176.49	0.3124	0.0002	0.0012	-0.0021	0.00336	3/15/00 1:35	0.31243	0.0001825	0.00336
26	3/15/00	3:57:48	36.75	0.0573	0.0000	-0.0001	-0.0021	0.002011	3/15/00 3:57	0.05731	2.906E-05	0.002011
27	3/17/00	6:32:57	26.50	0.0570	0.0000	0.0010	-0.0009	0.001896	3/17/00 6:32	0.05703	3.583E-05	0.001896
28	3/17/00	8:54:56	66.75	0.1458	0.0001	-0.0002	-0.0031	0.002894	3/17/00 8:54	0.14582	0.000109	0.002894
29	3/18/00	15:16:56	175.26	0.2936	0.0002	0.0012	-0.0015	0.00275	3/18/00 15:16	0.29359	0.0001573	0.00275
30	3/19/00	7:44:01	154.50	0.7484	0.0011	0.0006	-0.0028	0.00336	3/19/00 7:44	0.74837	0.001093	0.00336
31	3/22/00	9:57:13	25.54	0.0998	0.0001	0.0000	-0.0031	0.00305	3/22/00 9:57	0.09976	0.0001268	0.00305
32	3/22/00	19:41:37	93.49	0.1747	0.0001	0.0012	-0.0015	0.00275	3/22/00 19:41	0.17473	0.000113	0.00275
33	3/15/00	19:21:32	61.76	0.5230	0.0013	0.0110	-0.0037	0.01465	3/15/00 19:21	0.52301	0.001327	0.01465
34	3/15/00	19:22:34	30.99	0.2080	0.0006	0.0051	-0.0006	0.00571	3/15/00 19:22	0.20798	0.0005558	0.00571
35	3/15/00	19:24:01	63.51	0.6528	0.0020	0.0092	-0.0003	0.00947	3/15/00 19:24	0.65279	0.0019559	0.00947
36	3/15/00	19:37:58	35.78	0.2420	0.0004	0.0006	-0.0024	0.00305	3/15/00 19:37	0.24197	0.0004299	0.00305
37	3/16/00	12:32:13	23.49	0.0585	0.0000	0.0010	-0.0006	0.001587	3/16/00 12:32	0.0585	3.999E-05	0.001587
38	3/16/00	21:01:40	27.49	0.1681	0.0003	-0.0003	-0.0061	0.005759	3/16/00 21:01	0.16808	0.0003489	0.005759
39	3/16/00	21:04:46	16.74	0.0582	0.0001	0.0013	-0.0021	0.003435	3/16/00 21:04	0.05817	5.698E-05	0.003435
40	3/26/00	22:44:08	38.75	0.5584	0.0024	-0.0006	-0.0122	0.0116	3/26/00 22:44	0.55836	0.0024141	0.0116
41	3/26/00	22:45:41	63.00	0.7112	0.0026	0.0076	-0.0089	0.01648	3/26/00 22:45	0.71121	0.0026313	0.01648
42	4/4/00	1:42:04	38.01	0.6180	0.0029	0.0079	-0.0003	0.00824	4/4/00 1:42	0.61799	0.00295	0.00824
43	4/12/00	7:20:02	30.74	0.3146	0.0009	0.0076	0.0009	0.006727	4/12/00 7:20	0.31463	0.0009442	0.006727
44	4/4/00	13:21:54	22.99	0.4655	0.0054	-0.0018	-0.0232	0.021372	4/4/00 13:21	0.46547	0.0053953	0.021372
45	4/4/00	13:22:47	22.49	0.5588	0.0047	0.0070	-0.0189	0.025968	4/4/00 13:22	0.55881	0.0047029	0.025968
46	4/4/00	13:28:45	28.49	0.7743	0.0108	-0.0021	-0.0308	0.028743	4/4/00 13:28	0.77434	0.0107534	0.028743
47	4/4/00	13:30:37	39.24	2.2142	0.0411	0.0100	-0.0287	0.038696	4/4/00 13:30	2.21419	0.0410795	0.038696
48	4/4/00	16:09:16	84.49	1.0521	0.0044	0.0098	-0.0028	0.01252	4/4/00 16:09	1.05208	0.0044162	0.01252
49	4/4/00	16:21:12	38.25	0.5847	0.0032	0.0018	-0.0101	0.0119	4/4/00 16:21	0.58473	0.0031647	0.0119
50	4/4/00	16:42:41	92.23	1.2064	0.0054	0.0043	-0.0101	0.014382	4/4/00 16:42	1.2064	0.0054201	0.014382
51	4/4/00	19:28:42	19.01	0.1777	0.0005	0.0046	-0.0037	0.008234	4/4/00 19:28	0.1777	0.0004625	0.008234
52	4/4/00	21:42:11	25.75	0.2943	0.0010	0.0046	-0.0067	0.01129	4/4/00 21:42	0.29435	0.0009929	0.01129
53	4/4/00	21:50:36	48.51	1.2756	0.0101	-0.0009	-0.0143	0.01342	4/4/00 21:50	1.27562	0.0101203	0.01342
54												
55	4/5/00	21:21:15	41.49	0.6772	0.0035	0.0046	-0.0092	0.01374	4/5/00 21:21	0.67722	0.0035235	0.01374
56	4/5/00	22:24:41	125.24	2.0346	0.0115	0.0122	-0.0064	0.01862	4/5/00 22:24	2.03456	0.0114742	0.01862
57	4/15/00	21:08:23	33.51	0.1208	0.0002	0.0000	-0.0055	0.00549	4/15/00 21:08	0.12077	0.0001603	0.00549
58	4/17/00	21:09:00	24.25	0.0902	0.0001	-0.0004	-0.0040	0.003547	4/17/00 21:09	0.09024	0.0001151	0.003547
59	4/21/00	15:18:20	23.01	0.1467	0.0003	0.0049	0.0005	0.004367	4/21/00 15:18	0.14666	0.0002724	0.004367
60	4/21/00	15:19:10	24.50	0.1223	0.0002	-0.0003	-0.0049	0.00457	4/21/00 15:19	0.1223	0.0001758	0.00457
61	4/21/00	23:37:37	24.76	0.1204	0.0002	0.0006	-0.0058	0.00641	4/21/00 23:37	0.12041	0.0002333	0.00641
62	4/23/00	22:07:54	19.02	0.1066	0.0002	-0.0004	-0.0067	0.006264	4/23/00 22:07	0.10661	0.0002117	0.006264
63	4/27/00	17:22:49	23.17	0.1246	0.0002	0.0046	-0.0052	0.00977	4/27/00 17:22	0.12456	0.0002246	0.00977
64	4/27/00	20:03:17	37.00	0.5634	0.0027	0.0074	-0.0015	0.008914	4/27/00 20:03	0.56342	0.0026797	0.008914
65	5/1/00	18:06:48	23.49	0.0781	0.0001	-0.0003	-0.0031	0.002781	5/1/00 18:06	0.07808	8.532E-05	0.002781
66	5/1/00	22:23:13	54.49	1.1198	0.0066	0.0087	0.0007	0.008087	5/1/00 22:23	1.11979	0.0066438	0.008087
67	4/21/00	20:08:17	25.26	0.1238	0.0002	-0.0001	-0.0067	0.006604	4/21/00 20:08	0.12379	0.0002318	0.006604

68	4/22/00	7:27:41	25.23	0.1461	0.0003	-0.0005	-0.0067	0.006202	4/22/00 7:27	0.14605	0.0002597	0.006202
69	4/23/00	21:02:55	32.26	0.1601	0.0003	-0.0005	-0.0049	0.004379	4/23/00 21:02	0.16007	0.0002549	0.004379
70	4/24/00	6:49:41	27.76	0.1301	0.0002	-0.0005	-0.0052	0.004708	4/24/00 6:49	0.13007	0.0001792	0.004708
71	4/30/00	4:51:06	17.99	0.0732	0.0001	-0.0004	-0.0043	0.003861	4/30/00 4:51	0.07315	9.231E-05	0.003861
72	5/2/00	8:58:50	25.51	0.1120	0.0002	-0.0003	-0.0040	0.003661	5/2/00 8:58	0.11204	0.0001828	0.003661
73	5/4/00	4:22:17	17.76	0.0681	0.0001	-0.0002	-0.0037	0.003438	5/4/00 4:22	0.06813	8.205E-05	0.003438
74												
75	5/5/00	21:37:29	38.49	0.1554	0.0002	0.0003	-0.0055	0.0058	5/5/00 21:37	0.15543	0.0002417	0.0058
76	5/6/00	8:11:04	52.76	0.2557	0.0004	0.0009	-0.0043	0.00519	5/6/00 8:11	0.25569	0.0004278	0.00519
77	5/8/00	6:09:47	18.27	0.0643	0.0001	-0.0004	-0.0034	0.002997	5/8/00 6:09	0.06429	7.667E-05	0.002997
78	5/10/00	3:44:39	21.01	0.0822	0.0001	0.0006	-0.0037	0.00427	5/10/00 3:44	0.08219	0.000113	0.00427
79	5/13/00	19:49:58	27.24	0.1254	0.0002	-0.0003	-0.0055	0.005229	5/13/00 19:49	0.12542	0.0002103	0.005229
80	5/3/00	20:43:30	24.00	0.0652	0.0001	-0.0004	-0.0040	0.00358	5/3/00 20:43	0.06524	5.737E-05	0.00358
81	5/11/00	1:21:27	49.51	0.1880	0.0004	0.0040	-0.0006	0.004577	5/11/00 1:21	0.18804	0.0003379	0.004577
82	5/11/00	1:31:34	26.75	0.0767	0.0001	0.0034	0.0002	0.003172	5/11/00 1:31	0.07671	0.0001333	0.003172
83	5/11/00	2:04:13	33.76	0.1011	0.0001	0.0024	-0.0009	0.003372	5/11/00 2:04	0.10113	8.672E-05	0.003372
84	5/11/00	2:04:47	16.26	0.0287	0.0000	0.0021	-0.0007	0.002815	5/11/00 2:04	0.02871	1.952E-05	0.002815
85	5/11/00	3:11:12	28.26	0.1749	0.0009	0.0128	0.0003	0.01248	5/11/00 3:11	0.17485	0.0008733	0.01248
86	5/11/00	3:11:40	26.49	0.4912	0.0051	0.0150	0.0003	0.014611	5/11/00 3:11	0.49118	0.005118	0.014611
87	5/11/00	3:14:03	17.24	0.1566	0.0016	0.0165	0.0004	0.016104	5/11/00 3:14	0.15662	0.0016352	0.016104
88	5/11/00	3:15:27	17.00	0.0895	0.0007	0.0186	0.0004	0.01822	5/11/00 3:15	0.08945	0.0007163	0.01822
89	5/11/00	3:15:48	45.52	0.2869	0.0022	0.0205	0.0004	0.020014	5/11/00 3:15	0.28692	0.0022069	0.020014
90	5/11/00	3:16:41	29.99	0.2524	0.0028	0.0220	0.0005	0.021504	5/11/00 3:16	0.25237	0.0028367	0.021504
91	5/11/00	3:17:12	20.75	0.2009	0.0030	0.0232	0.0005	0.022676	5/11/00 3:17	0.2009	0.0029534	0.022676
92	5/11/00	3:20:42	32.00	1.6812	0.0439	0.0351	0.0005	0.034598	5/11/00 3:20	1.68122	0.0438687	0.034598
93	5/11/00	3:21:14	59.99	0.9700	0.0155	0.0357	0.0008	0.034898	5/11/00 3:21	0.96999	0.0154834	0.034898
94	5/11/00	3:22:58	26.00	1.0990	0.0365	0.0409	0.0008	0.040122	5/11/00 3:22	1.09898	0.0364949	0.040122
95	5/11/00	3:25:11	26.27	1.1493	0.0442	0.0531	0.0008	0.052331	5/11/00 3:25	1.14931	0.0442141	0.052331
96	5/11/00	3:25:38	20.75	0.3423	0.0102	0.0461	0.0009	0.045219	5/11/00 3:25	0.34235	0.0101822	0.045219
97	5/11/00	3:28:18	32.75	2.2719	0.1096	0.0559	0.0008	0.0551	5/11/00 3:28	2.27188	0.109621	0.0551
98	5/11/00	5:25:21	17.00	0.1345	0.0040	0.0449	-0.0010	0.045826	5/11/00 5:25	0.13453	0.0039775	0.045826
99	5/11/00	6:26:23	19.00	0.1466	0.0035	0.0348	-0.0010	0.035826	5/11/00 6:26	0.1466	0.0034527	0.035826
100	5/11/00	6:27:07	23.74	0.2917	0.0076	0.0345	-0.0010	0.035513	5/11/00 6:27	0.29174	0.0075755	0.035513
101	5/11/00	6:33:20	21.76	0.2432	0.0058	0.0357	0.0004	0.03531	5/11/00 6:33	0.24324	0.0057963	0.03531
102	5/11/00	8:23:09	64.73	2.9054	0.0906	0.0342	-0.0011	0.035244	5/11/00 8:23	2.90538	0.0905786	0.035244
103	5/11/00	8:30:53	31.51	0.3974	0.0103	0.0333	-0.0009	0.034173	5/11/00 8:30	0.39738	0.0103442	0.034173
104	5/11/00	8:38:41	20.74	0.6546	0.0194	0.0327	-0.0007	0.033372	5/11/00 8:38	0.65464	0.0193673	0.033372
105	5/11/00	9:04:44	26.51	0.1637	0.0028	0.0311	-0.0010	0.032154	5/11/00 9:04	0.1637	0.002759	0.032154
106	5/11/00	9:32:37	26.51	0.3511	0.0091	0.0314	-0.0008	0.032221	5/11/00 9:32	0.35106	0.0091219	0.032221
107	5/11/00	9:39:16	42.25	0.2657	0.0053	0.0299	-0.0009	0.030839	5/11/00 9:39	0.26571	0.005273	0.030839
108	5/12/00	13:23:18	133.25	14.7971	0.4636	0.0333	-0.0012	0.034493	5/12/00 13:23	bad data	bad data	0.034493
109	5/17/00	3:48:40	26.25	2.2697	0.1302	0.0601	-0.0012	0.061361	5/17/00 3:48	2.26973	0.130199	0.061361
110	5/18/00	12:11:27	47.74	6.4739	0.4035	0.0650	0.0003	0.064697	5/18/00 12:11	bad data	0.403494	0.064697
111	5/18/00	19:34:06	22.24	1.0767	0.0652	0.0656	-0.0012	0.066851	5/18/00 19:34	1.07666	0.0651538	0.066851
112	5/18/00	23:48:16	100.00	21.9790	1.4366	0.0687	0.0004	0.068304	5/18/00 23:48	bad data	bad data	0.068304
113	5/19/00	2:45:54	37.99	4.0413	0.2551	0.0659	-0.0011	0.067001	5/19/00 2:45	4.04134	0.255132	0.067001
114	5/19/00	2:48:36	18.76	0.3834	0.0213	0.0656	0.0004	0.065238	5/19/00 2:48	0.38345	0.0213361	0.065238
115	5/20/00	16:54:07	62.51	11.8027	0.8220	0.0726	-0.0015	0.074144	5/20/00 16:54	bad data	bad data	bad data
116	5/20/00	16:58:01	22.00	1.6958	0.1169	0.0726	0.0003	0.072298	5/20/00 16:58	1.69583	0.116927	bad data
117	5/20/00	19:23:01	22.25	0.4898	0.0316	0.0732	0.0004	0.072831	5/20/00 19:23	0.48977	0.0315606	bad data
118	5/20/00	19:52:51	22.50	0.9831	0.0658	0.0723	-0.0013	0.073608	5/20/00 19:52	0.98308	0.0658314	bad data
119	5/21/00	5:40:41	33.76	2.8608	0.2094	0.0775	-0.0011	0.078653	5/21/00 5:40	2.86083	0.209414	bad data
120	5/21/00	9:18:21	23.01	1.9969	0.1486	0.0794	0.0003	0.079087	5/21/00 9:18	1.9969	0.148576	bad data
121	5/21/00	9:22:15	20.74	1.4439	0.1069	0.0790	0.0003	0.078706	5/21/00 9:22	1.44389	0.106855	bad data
122	5/18/00	7:39:38	20.00	0.0943	0.0001	-0.0003	-0.0031	0.00274	5/18/00 7:39	0.09425	0.0001284	0.00274
123	5/18/00	8:08:54	20.01	0.0692	0.0001	0.0021	-0.0015	0.00367	5/18/00 8:08	0.06917	6.672E-05	0.00367
124	5/18/00	8:20:57	18.24	0.0658	0.0001	0.0028	0.0004	0.002384	5/18/00 8:20	0.06583	6.726E-05	0.002384
125	5/19/00	10:47:59	18.50	0.0603	0.0001	0.0018	-0.0006	0.00244	5/19/00 10:47	0.06026	5.411E-05	0.00244
126	5/19/00	12:12:15	19.26	0.0704	0.0001	0.0031	-0.0009	0.00397	5/19/00 12:12	0.07035	7.638E-05	0.00397
127	5/19/00	16:12:01	20.27	0.0810	0.0001	0.0018	-0.0015	0.003357	5/19/00 16:12	0.08097	8.362E-05	0.003357
128	5/19/00	18:14:16	22.48	0.0975	0.0001	0.0028	-0.0006	0.00336	5/19/00 18:14	0.09754	0.0001221	0.00336
129	5/19/00	18:26:37	23.00	0.1179	0.0002	-0.0003	-0.0019	0.001633	5/19/00 18:26	0.11792	0.000163	0.001633
130	5/19/00	18:40:52	25.02	0.1236	0.0002	-0.0003	-0.0024	0.002097	5/19/00 18:40	0.12361	0.0001627	0.002097
131	5/19/00	18:52:47	20.75	0.0755	0.0001	0.0015	-0.0024	0.00397	5/19/00 18:52	0.07551	7.664E-05	0.00397
132	5/19/00	18:54:41	36.26	0.1453	0.0002	0.0024	-0.0024	0.00488	5/19/00 18:54	0.1453	0.0001786	0.00488
133	5/19/00	18:58:39	168.99	1.0802	0.0022	0.0046	-0.0018	0.00641	5/19/00 18:58	1.08022	0.0022038	0.00641
134	5/19/00	19:36:16	39.74	0.1755	0.0002	0.0012	-0.0031	0.00427	5/19/00 19:36	0.17546	0.0002187	0.00427
135	5/19/00	23:01:58	18.26	0.0752	0.0001	-0.0003	-0.0018	0.00152	5/19/00 23:01	0.07521	8.507E-05	0.00152

136	5/19/00	23:06:43	44.63	0.2073	0.0003	0.0028	-0.0037	0.00641	5/19/00 23:06	0.2073	0.0003013	0.00641
137	5/20/00	3:11:16	105.13	0.2995	0.0003	0.0028	-0.0037	0.00641	5/20/00 3:11	0.29947	0.0003104	0.00641
138	5/20/00	3:39:55	23.51	0.0788	0.0001	0.0018	-0.0012	0.00305	5/20/00 3:39	0.07877	7.168E-05	0.00305
139	5/20/00	8:37:49	26.51	0.0985	0.0001	0.0034	-0.0015	0.00489	5/20/00 8:37	0.0985	0.0001092	0.00489
140	5/21/00	11:53:31	103.24	0.3714	0.0005	0.0034	-0.0034	0.00672	5/21/00 11:53	0.37142	0.0004629	0.00672
141	5/21/00	15:09:00	33.76	0.1264	0.0002	0.0024	-0.0024	0.00488	5/21/00 15:09	0.12644	0.0001521	0.00488
142	5/21/00	15:35:37	17.51	0.0825	0.0001	0.0028	0.0006	0.002181	5/21/00 15:35	0.08249	0.0001054	0.002181
143	5/21/00	16:01:42	166.75	1.1138	0.0023	0.0040	-0.0015	0.0055	5/21/00 16:01	1.11381	0.0023116	0.0055
144	5/21/00	17:11:21	19.76	0.0649	0.0001	0.0024	-0.0006	0.00305	5/21/00 17:11	0.06495	6.308E-05	0.00305
145	5/21/00	17:31:54	35.76	0.1207	0.0001	0.0028	-0.0021	0.00489	5/21/00 17:31	0.12069	0.0001308	0.00489
146	5/21/00	20:49:59	33.95	0.1268	0.0002	0.0034	-0.0021	0.0055	5/21/00 20:49	0.12684	0.0001629	0.0055
147	5/21/00	20:51:41	17.24	0.0631	0.0001	0.0012	-0.0018	0.00305	5/21/00 20:51	0.06308	6.36E-05	0.00305
148	5/22/00	0:10:22	34.00	0.1506	0.0002	0.0021	-0.0015	0.00367	5/22/00 0:10	0.15059	0.0001912	0.00367
149	5/22/00	4:25:24	23.50	0.1008	0.0001	-0.0004	-0.0031	0.002671	5/22/00 4:25	0.10085	0.0001217	0.002671
150	5/22/00	7:40:49	21.24	0.0926	0.0001	0.0037	0.0005	0.003184	5/22/00 7:40	0.09263	0.0001181	0.003184
151	5/22/00	7:52:15	161.74	0.5966	0.0008	0.0031	-0.0031	0.0061	5/22/00 7:52	0.59662	0.0007918	0.0061
152	5/22/00	7:55:19	127.99	0.8470	0.0017	0.0040	-0.0018	0.0058	5/22/00 7:55	0.84698	0.0017409	0.0058
153	5/22/00	8:09:00	37.25	0.2117	0.0004	0.0049	-0.0015	0.00641	5/22/00 8:09	0.2117	0.0003666	0.00641
154	5/22/00	8:22:06	84.49	0.3054	0.0004	0.0034	-0.0028	0.00611	5/22/00 8:22	0.30538	0.0003851	0.00611
155	5/22/00	8:35:34	38.24	0.1803	0.0002	0.0031	0.0006	0.00249	5/22/00 8:35	0.18026	0.0002366	0.00249
156	5/22/00	8:49:27	23.24	0.1146	0.0002	0.0031	-0.0003	0.00336	5/22/00 8:49	0.1146	0.0001519	0.00336
157	5/22/00	9:02:57	24.39	0.1324	0.0002	0.0003	-0.0024	0.00275	5/22/00 9:02	0.13239	0.0001862	0.00275
158	5/22/00	9:16:16	30.25	0.1509	0.0002	0.0009	-0.0031	0.00397	5/22/00 9:16	0.15089	0.0002168	0.00397
159	5/22/00	9:33:42	170.26	1.1721	0.0025	0.0043	-0.0015	0.0058	5/22/00 9:33	1.17209	0.0024733	0.0058
160	5/22/00	9:48:12	19.27	0.0893	0.0001	0.0028	0.0005	0.002204	5/22/00 9:48	0.08926	0.0001186	0.002204
161	5/22/00	9:57:00	64.24	0.2384	0.0003	0.0024	-0.0024	0.00488	5/22/00 9:57	0.23838	0.0002904	0.00488
162	5/23/00	16:12:16	28.75	0.1295	0.0002	-0.0004	-0.0024	0.002025	5/23/00 16:12	0.12952	0.0001575	0.002025
163	5/23/00	16:56:17	35.50	0.1646	0.0002	0.0019	-0.0024	0.004338	5/23/00 16:56	0.16458	0.0002103	0.004338
164	5/23/00	17:08:31	79.52	0.3211	0.0004	0.0028	-0.0037	0.00641	5/23/00 17:08	0.32115	0.0004299	0.00641
165	5/23/00	17:09:51	23.50	0.0963	0.0001	0.0037	-0.0003	0.00397	5/23/00 17:09	0.09633	0.0001135	0.00397
166	5/23/00	17:55:07	24.51	0.0888	0.0001	0.0021	-0.0031	0.00519	5/23/00 17:55	0.08884	9.794E-05	0.00519
167	5/23/00	18:32:01	21.01	0.1015	0.0001	0.0037	-0.0003	0.00397	5/23/00 18:32	0.10153	0.0001476	0.00397
168	5/23/00	19:53:08	23.24	0.0794	0.0001	0.0009	-0.0037	0.00458	5/23/00 19:53	0.07941	8.703E-05	0.00458
169	5/24/00	1:23:14	18.01	0.0554	0.0001	0.0037	0.0003	0.003328	5/24/00 1:23	0.05543	5.384E-05	0.003328
170	5/24/00	4:55:55	134.76	0.4749	0.0006	0.0034	-0.0028	0.00611	5/24/00 4:55	0.47489	0.0005705	0.00611
171	5/24/00	6:13:09	17.74	0.0505	0.0000	0.0011	-0.0015	0.00259	5/24/00 6:13	0.05046	3.886E-05	0.00259
172	5/24/00	20:30:20	19.49	0.0509	0.0000	0.0012	-0.0021	0.00336	5/24/00 20:30	0.05086	4.016E-05	0.00336
173	5/26/00	15:27:22	26.24	0.0828	0.0001	0.0031	-0.0009	0.00397	5/26/00 15:27	0.08278	8.955E-05	0.00397
174	5/26/00	18:31:49	22.26	0.0639	0.0001	0.0028	0.0003	0.00244	5/26/00 18:31	0.06393	5.422E-05	0.00244
175	5/26/00	18:46:20	21.25	0.0699	0.0001	-0.0003	-0.0021	0.00183	5/26/00 18:46	0.06988	6.414E-05	0.00183
176	5/30/00	16:12:59	29.75	0.0974	0.0001	0.0024	-0.0015	0.00397	5/30/00 16:12	0.09742	9.893E-05	0.00397
177	5/30/00	16:37:31	16.50	0.0497	0.0000	0.0024	0.0003	0.00213	5/30/00 16:37	0.04973	4.359E-05	0.00213
178	5/30/00	19:12:41	18.01	0.0624	0.0001	0.0021	-0.0012	0.00336	5/30/00 19:12	0.06238	5.997E-05	0.00336
179	5/30/00	19:49:45	18.76	0.0533	0.0000	0.0006	-0.0018	0.00244	5/30/00 19:49	0.05333	4.215E-05	0.00244
180	5/30/00	21:26:53	52.00	0.1648	0.0002	0.0021	-0.0028	0.00489	5/30/00 21:26	0.16477	0.000166	0.00489
181	5/30/00	21:44:22	35.74	0.1563	0.0002	0.0018	-0.0031	0.00488	5/30/00 21:44	0.15627	0.0002014	0.00488
182	5/30/00	22:27:05	27.98	0.1018	0.0001	0.0024	-0.0021	0.00458	5/30/00 22:27	0.10179	0.0001101	0.00458
183	5/30/00	22:59:33	166.99	0.6654	0.0009	0.0037	-0.0015	0.00519	5/30/00 22:59	0.66542	0.000929	0.00519
184	5/31/00	0:37:16	19.50	0.0590	0.0001	0.0012	-0.0024	0.003603	5/31/00 0:37	0.05905	5.172E-05	0.003603
185	5/31/00	0:43:44	28.99	0.0921	0.0001	0.0006	-0.0028	0.00336	5/31/00 0:43	0.09206	8.724E-05	0.00336
186	5/31/00	0:57:27	16.75	0.0589	0.0001	-0.0005	-0.0018	0.001353	5/31/00 0:57	0.05892	5.54E-05	0.001353
187	5/31/00	1:12:47	134.51	0.4961	0.0006	0.0034	-0.0024	0.0058	5/31/00 1:12	0.4961	0.0006459	0.0058
188	5/31/00	7:19:13	27.56	0.0891	0.0001	0.0024	0.0002	0.002228	5/31/00 7:19	0.08909	8.2E-05	0.002228
189	5/31/00	8:38:56	19.26	0.0597	0.0001	0.0024	-0.0018	0.00427	5/31/00 8:38	0.05965	5.495E-05	0.00427
190	5/31/00	8:47:37	16.26	0.0545	0.0000	-0.0004	-0.0018	0.001401	5/31/00 8:47	0.05446	4.92E-05	0.001401

MAX	211.0140	21.9790	1.436630
MIN	16.2640	0.0074	0.000001
Average	50.7305	0.8444	0.028503
Standard Deviation	48.8071	2.4079	0.131676

0.0791	4.0413
0.0001	0.0074
0.0142	0.4301
0.0192	0.6286

Accumulated Pitting Charge

A scatter plot showing the relationship between PIC Rate (special units) on the y-axis and CP (V) on the x-axis. The y-axis ranges from 0 to 29,000 with major ticks every 5,000 units. The x-axis ranges from -0.25 to 0 with major ticks every 0.025 units. The plot contains 1,000 data points represented by black diamonds. A dense vertical cluster of points is located at CP = 0, spanning the entire range of PIC Rate. Other points are scattered across the plot, with notable concentrations at CP values of approximately -0.1, -0.125, -0.15, -0.175, -0.2, -0.225, and -0.25. A dashed grid is overlaid on the plot.