

**Statistical Process Control Methods in
Performance Monitoring**

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I. Executive Summary

This paper seeks to expose the benefits of using statistical process control (SPC) methods in performance monitoring. It does not (apart from the appendices) explain statistical methods but attempts to unveil the benefits.

Note: SPC will be used as an abbreviation for statistical process control

The benefits of Statistical Process Control in performance monitoring have to an extent been utilized throughout the utility industry. Almost every performance engineer has at one time or another trended an instrument to help him understand a process. We all look at a graph of plant heat rate and use the information to trigger an investigation as to why it is increasing or decreasing. This paper discusses an expansion of existing methods and a few new "tools of the trade" to help performance engineers control their process.

By controlling the process we can effect changes to make that process better. The process that the performance engineer seeks to control and make more efficient is generating electricity. The principal indicator that defines the quality of the process is heat rate. Not only do we desire to keep the process from getting worse, but we seek to improve the process. For example if we accept an increasing heat rate through a fuel cycle due to various reasons then we are missing the point of controlling the process. We may only be able to affect the slope of the heat rate, but we must apply our knowledge and tools with the goal to continually make our product higher quality. If we can show which variables have the greatest affect on the process then we will be better able to get the support for the changes we want to institute.

The SPC tools have been applied at Peach Bottom and at PaloVerde independently and have shown to be useful in the Thermal Performance programs in each of these Nuclear generating stations.

II. What is SPC

A. History

Back in the 1950s, Japan experienced a revolution in the way they did business. The post war era Japanese products had a horrendous reputation for low quality. "Made in Japan" became a synonym for poorly made products; junk. Japan reformed their ways of doing things by donning a new way of doing business, embracing the teachings of W. Edwards Deming. Deming was the

evangelist for the use of statistical methods in controlling the quality of production. This new way highlighted the use of statistics in quality improvement. The basic tenet was that the final quality is assured if the quality of each incremental phase of production is controlled. The paradigm shift required was that it was not only necessary for the final product to function well (predominantly and formerly monitored by final spot inspections), it was vital for each incremental phase be performed in a quality fashion. In other words, if the production process is incrementally monitored for quality then the final quality was a given. The final inspection technique could, and should, be mitigated or done away with because it would no longer be necessary to assure quality. In the States, statistical methods are gaining popularity as useful tools for monitoring processes, and incrementally improving product quality. Du Pont, Eastman Kodak, Xerox, Bell Labs, and Hewlett Packard, to name a few, have large statistics branches to serve this effort.

We submit that the same methods may be applied to the many processes in the nuclear power industry. In fact, several utilities (e.g. Florida Power) have employed these techniques, to increase the effectiveness of their service. Though their changes have been vastly human resource and support systems intensive, the techniques have been introduced and have become familiar. It would not be a long stretch to creatively assimilate them into plant/system/component performance monitoring. We propose that the same principles and techniques have applicability in increasing the quality (reliability, efficiency, etc.) of the major nuclear plant product; electricity. Granted, the process of producing electricity is different from the processes and products of the manufacturing industry. In the power production industry we are monitoring an energy conversion process. You can not measure the quality of a Megawatt. However, you can monitor how efficiently you convert heat to electricity. These differences should be recognized and understood and the application of the SPC should be adjusted accordingly. SPC provides standard methods of dealing with data which is a necessary evil for performance engineers. How to analyze, interpret and communicate data is of paramount importance and the purpose of statistics. Collectively the use of statistical methods to achieve quality are referred to as Statistical Process Control (SPC). Use of these techniques have been successful at both Peach Bottom and Palo Verde.

Here are a couple of examples to give a feel for what we are talking about. In automobile manufacturing, SPC may be employed to maintain the quality of machined parts or the time required to perform an activity. Continual quality improvement is played out in having fewer defective parts or putting systems in place to make an activity more efficient. Likewise, an example of a power plant application may be to formulate a set of parameters (performance indicators) that would provide insight into performance deviations (final feedwater temperature, turbine first stage pressure, et al). Continual quality

improvement may be played out in instrument modifications, to increase accuracy, repeatability and sensitivity, or operations procedures may be altered to improve efficiency during load drops.

B. THE OLD WAY - REACTIVE:

1. *Fire Fighting*- we are forced to address only those problems which have the most immediate management attention.
2. *Short Term*- We spend all our time on acute symptoms and no time on the chronic disease.
3. *Expedites*- A lot of money is spent on overtime and expediting an issue.
4. *Delays*- Because we were not able to see problems developing outages and downpowers occur.
5. *Rework*- Instead of finding the real problem (root cause) we have to revisit an issue time and time again.

C. SPC - PROACTIVE

1. *Education*- Understand the basics of the process
2. *Awareness*-Take the time to be aware of all the major variables in the process
3. *Long Term Planning*- Plan so you can improve the process rather than you being controlled by the process.
4. *Prevention*- Bring the process in control so you can detect problems early on and prevent them from becoming larger and more expensive.
5. *Evaluation*- When you are in control of the process you can then evaluate it and improve it.

D. We see the production of electricity as a process and then define the various inputs and outputs of the process.

The process of electrical production has many variables. Some of those variables the performance engineer can control and some he cannot. The first step is to define those aspects of the process that can be controlled. The ones which cannot be controlled should be removed from the analysis of the process. Once you decide which variables you can control you take ownership of those variables. In deciding which variables to get involved in you have to be creative yet realistic. For instance operator training. Much of our time is spent in convincing operators how to run the plant in an efficient way. Some operators do well others do not. It appeared that our hands were tied in this situation, this seemed to be a variable we could not control. Then we requested permission to participate in the training process of the operators. Now we can affect the knowledge level of the operators by getting involved in their process. Of course, the affect we have is a function of how much time we can spend with them in training or how much money we have to purchase training programs. We have to limit our control of that variable based on the

return that we think we can receive.

There are some variables that we might have a significant amount of control over if we had the ability to monitor them. In the fossil plant world we call these controllable parameters. Having a set of controllable parameters to monitor gives you good control of the process. However, in the Base loaded Nuclear world we have very few controllable parameters. The definition of how we can affect our process is much more complicated and much more limiting. In these days of limited capital budgets and operating & maintenance reduction programs, we cannot expect to institute expensive design changes even if we can show a payback. It is imperative that we understand the process very well and seek to improve it in less costly ways.

Once you have defined your process and which variables you have ownership of, you must devise a way to monitor those variables. SPC provides a method to monitor the process variables. It is a set of tools designed to inform when a process variable has changed. Once the change is detected by SPC, other tools can be used to correct and or quantify the affect on the process

E. A change must occur in our way of thinking about thermal performance.

Apart from the initial hurdle that requires the performance engineer to change his way of thinking, there are some major paradigms shifts to facilitate with the rest the plant world. SPC will be a different way of doing business, requiring people to willingly assume a different perspective.

Two Prevalent Paradigms need to be addressed (others exist):

1. *"We should be able to accurately measure the inefficiencies absolutely."*

What is assumed here is that plant instrumentation accurately reflect the processes that they measure. Typically, absolute value producing programs (Megawatt Accounting) cause people to loop through the disbelief phases over and over again. First the accuracy of the instrumentation is questioned, then the accuracy of the program or model is reviewed, then supporting data is gathered, then operational anomalies are checked for, finally acceptance of the problem sets in and the associated work to correct it. For most of the plants that we have polled, BOP instrumentation always plays second fiddle to the safety related and reactor support instruments, which means that it is inevitably inaccurate, or at least of questionable accuracy. This situation may only get worse due to the industry wide corporate downsizing efforts.

Use of SPC methods will, in most cases, save time since the first step is to believe the problem, not to question all of the supporting systems. This is achieved through the ready source of supporting data (i.e. a MW deviation in this performance indicator should produce a MW deviation in another). The

use of performance indicators is almost self governing. For instance, if the condenser fouling performance indicator identifies a loss, it is very simple to check for a related heat rate shift and whether it has the same characteristic trend (so allaying it with condenser fouling).

The impetus should be to question instrumentation last, not first. SPC methods virtually negate the absolute accuracy of the instrumentation, depending primarily on sensitivity and repeatability characteristics which has been reliable. Though periodic instrument calibrations and check-outs are needed, it is certainly an advantage to not need the instrumentation to be absolutely accurate all of the time.

2. *“Statistical methods seem to complicate matters.”*

Poorly executed transitions toward using SPC will produce this result. The culture has to be changed to accept SPC. Additionally, it goes against the grain, especially for those who have developed their mental databases, to trust something else, when their tried and true way has served them so well for so many years. The tendency for many is retreat to their mental residence in Missouri. Secondly, statistical methods are not at first intuitive. There is a trade jargon that the neophyte statistician may use a bit too liberally, therefore worsening his chances for SPC to be adopted and embraced rather than helping it to gain acceptance.

F. **Why we use control Charts**

Control Charts are statistical tools to help monitor a process. The control charts help determine whether a process is in statistical control. Being in statistical control can mean different things depending on the process and the data available. Generally, statistical control is a function of the variability in the process. All processes have some degree of variability, some natural and some unnatural. Natural variability is background noise. In performance related data there is a large degree of background noise. The difficult task is to separate the natural variability from the unnatural variability. When we remove all the unnatural variabilities then our process is said to be in control. Therefore the first step in SPC is to bring the process into a state of control. Once the process is in control then we can monitor the process to see when it goes out of control, pinpoint the variable that has driven it out of control, and take corrective action.

Whether or not a process is in control in the performance world is somewhat of a relative matter. In the manufacturing world, the engineers have good control of the variables in their process. In a power plant not only are there a tremendous amount of variables but many of them are out of the performance engineers control. Sometimes if we cannot control a variable we can at least correct for it. This is the purpose of the “Performance Indicators” at Peach Bottom and the correction curves at Palo Verde. By using numerical methods

we can correct for many of the variables that we cannot control. Using existing correction curves such as the GE curves for condenser backpressure and computer models (such as PEPSE) we can develop equations which define the affect of a parameter on the process. Using these methods we can bring our process into control even though initially the variability was very high.

III. Why do we need SPC?

A. Too much data to keep in mind to perform effective analysis.

Have you every wondered whether the magnitudes of the losses reported by performance engineers is real? They seem to change week to week. You may ask, "Are these guys taking into account instrument inaccuracy and power level before they report on these problems?" "Is their plant modelling program accurate?" "Can I really believe this information?" These are all common questions that, as surprising as it may seem, even the performance engineer himself grapples with day in and day out. His job is typically more of a highly skilled interpreter than purely theoretical engineering. Some performance engineers would like us to believe that there is something esoteric in their ability. In an almost magical way, they divine the solution to various plant problems. We contend that this seemingly special ability is simply a crude form of SPC, imprecise and mental in nature. It's like this, every performance engineer has compiled a mental database of normal operating values for various plant parameters. As information comes in, he then matches this data against the values that he expects. Almost unconsciously, he makes a personal judgement regarding the severity of the deviation (in SPC'ese this would be the z value). If a deviation is too large, then a mental bell goes off and he shifts into troubleshooting mode. This happens whether or not your company has an SPC model up and running. It is human nature. The difference that performing SPC offers is shared knowledge, low reliance on mental databases, measurable deviations and standard ways of analyzing and communicating data. It reduces the need for professional opinions (gut feelings).

B. SPC can be automated to allow full utilization of the power of a computing environment.

Computers have become a very useful tool for the performance engineer. Many statistical programs are available on various platforms to aid in SPC. It is possible to automate much of the statistical processes. This will insure that what you are analyzing is already corrected for the uncontrollable variables. These programs can be set up so that an audible or a visible alarm can be given if a process is moving out of control. Even though these programs are available and can perform a large quantity of the number crunching, it is very important for the performance engineer to be involved in the setting up of

these programs. They must always be aware of and understand all the calculations being performed. To give an inexperienced person the tool of statistical process control, without complete understanding of what is being calculated, or of the process, is inviting disaster. This is not something which is set up, turned on, and forgotten about. Continuous improvement (though buzz word) must be adhered to when using statistical process control.

C. The existing tools are inadequate for the resolution and quality expected by management.

In the past, a 1% loss may have been acceptable but now, no quantifiable loss is acceptable. As performance engineering has developed over the years, many tools have been added to the performance engineers tool box: better process instrumentation, accurate modelling of the secondary cycle, computer spreadsheets and data bases. With these tools has come an expectation of quicker and better answers. Now with the use of SPC is the ability to know the problem before it becomes a really big problem. The competitive environment the utility industry has been thrust into, has necessitated a better resolution in our evaluation ability. SPC gives the ability to look for small changes in the process. Previously, we had to wait for a drastic change in heat rate before we were alerted to investigate a problem. By using SPC methods, not only can a small shift in the heat rate be detected, but the variables affecting the process can be quickly evaluated to see what has caused the shift. All this being said, it is important to point out that SPC is still only a tool; the quality of the product still rests in the hands of the worker using the tool. Better tools in inexperienced hands can do more damage than good. Better tools in experienced hands will result in a higher quality product.

D. Not having the ability to scan the whole data picture has led to "Red herding" chases.

Intelligence is actually built into the SPC process. As any performance engineer understands, very seldom is a problem simple. Invariably there are many "false indications" which we spend our time chasing after before we realize that they were not the source of the problem. The corrections that are made to the data, will automatically rule out many indications, thereby saving time in the analysis of problems. Much like an artificial intelligence program, the combination of a 2 sigma analysis and control charts can act as an effective filter for many of these false indications.

E. The development of SPC forces a more complete understanding of the process and what affects it.

By all this, we do not mean that the performance engineers position can then

be reduced to a computer program that spits out deviations. There is much more to the position which is outside the scope of this paper to explore. Among these, however, are a well developed understanding of how the station operates (how it throbs), strong component oriented knowledge, computer knowledge, et al. This knowledge is very important and may not be repeatable by even the best algorithms, no matter how hard we try with our expert system driven programs. This is what a performance engineer should be bringing to the game, not an uncontrolled database that is inaccessible to all but him. Regarding this uncontrolled mental database, SPC method can provide the means for placing it in control and sharing the knowledge. SPC is only as good as the people who develop it. As we develop the program we will be forced to think about all the things that can affect heatrate rather than only what we traditionally consider.

- F. The more we understand the process the better we will be able to build a realistic computer model.**

The understanding gained during the development phase of an SPC program has the added benefit of better computer modelling. One of the dangers of using computer models in thermal performance is passive reliance on them. When we rigorously and critically look at the process we can take that knowledge and apply it to our existing computer model. This is an iterative process because we also use our computer model to help correct for uncontrolled variables. For instance at Palo Verde when correcting first stage pressure for changes in steam generator pressure, we were forced to look more closely into how throttle pressure ratio was modeled. Not only can the computer model itself benefit from SPC, but what we input to the model is benefited by knowing what really does affect the process so we don't waste time modelling.

IV. Program Development

- A. First step: Identify parameters that should be consistent**

A good example is condenser heat load. The expected heat load should simply be a function of the thermal power. The actual heat load will be the product of the circulating water flow and the differential temperature across the water boxes. A performance indicator that relates the expected and the actual could then be formulated by subtracting the expected from the actual. If this indicator decreases it may be identifying a bypass valve or other main steam related leak that is finding its way to the condenser, or it could signal a change in turbine efficiency. With either case, the performance engineer is quick to pick it up and isolate the problem using supporting performance indicators.

Notice that the target values may not make absolute sense. For instance, the target value for condenser heat load performance indicator at Peach Bottom is negative 5.5 MWe. This, in absolute terms, identifies that the condenser is accepting 5.5 MWs (this would be ~ 16.5 MWth) less than it should be; could the cycle be this much more efficient? Odds are that it is not but that one of the waterbox temperature elements is out of calibration or not positioned appropriately to give a correct indication of temperature. If our MW deviation changes to 0 MW (in an absolute sense), it would appear that we were doing well, operating right on the design point, however, our system tells us that we can pick up another 5.5 MWs somewhere in the bypass valves or in the turbine. So we go to work in spite of what looks wonderful. The target values reflect instrument error (inaccuracy and less than perfect placement) as well as other fixed system offsets.

Another way to develop a system of performance indicators may be to limit your data population to a certain operating band. For most nuclear plants this band may be all data above 99.5% power, since most plants run base loaded. Given this criteria, most power level dependent raw data points will be constant enough to identify deviations without any conditioning at all. This technique has proven to be very useful in spotting problems before they became significant.

B. Second step- Establish systems that allow you to maintain proper cognizance.

At both stations, performance is evaluated daily. It is vitally important that the data be high quality. Time averaged values or use of sample populations are both adequate methods for assuring quality data. It is easy to side step this in favor of getting the news out. Take the time to preclude the garbage in, garbage out cycle.

Another issue is the formulation of the program and objectives. Several documents are suggested to communicate the objectives of the performance monitoring program. They will be invaluable during responsibility transfers as well as a source for problem identification.

1. Project Overview, Normalization, and Design (if starting from scratch)

This document should outline the milestones, resources, and other project control information. It can also serve as a repository for thoughts regarding data file specifications and overall design. This is a perfect place to explore the data flow and availability at the station; make your system as efficient as possible.

2. Plant Performance Indicators

This document should express the intent and formulation of the plant performance indicators. Many of the esoteric elements of the performance engineers job may be mapped out in detail here. It houses the reasons for monitoring various parameters. Remember, all of your performance indicators should be formulated to identify a specific problem or set of problems.

3. Data Gathering, Analysis, and Presentation

It is important to specify where the data will be coming from, how it will be processed, and finally how it will be presented. This is where the outputs and formulations of various methods are developed. Also, it is important to discuss how to use the various tools in this tool box.

C. Third Step: Use the system.

Given that your station has a commitment to monitoring plant performance, regularly review the information. Do not develop a system and just crunch out graphs. You must be able to convert your results into recommendations for operations, maintenance and design changes. There are many examples of performance monitoring systems developed, where the engineer spends all his time producing wonderful graphs but no time analyzing. It will be difficult at first to convince people to take action based on statistical methods. We have found that the best way to convince people is to show results. When a problem is found based on the use of SPC advertise it. Remember, it may take a little evangelism to really make it fly.

V. SPC Methods

Here comes the jargon we warned you about. Hopefully it will provoke further investigation rather than thwart it. There are several SPC methods for identifying plant related problems. Some are intuitively obvious, others will require assimilation (reading, meditation, and use). Some of the building blocks for SPC (mean, standard deviation, etc.) are briefly discussed in the appendix along with examples of the different charts.

A. Trend Charts

Probably the most intuitive and familiar is the Trend Chart. This tool relies on the ability of man to process visual information and identify patterns. Its shortfall is that it does not aid in decision making. It is left to the individual to register the trend and determine its impact. One enhancement that can be made is the fitting of a regression line to clearly identify the trend.

B. Control Charts

The second most intuitive tool is the control chart (I chart or individuals chart). Control charts work similarly to trend charts with the distinction that they help the user identify data that is going awry. This is done by visually

identifying bounds that are set statistically; i.e. the bounds are floating limits that are set by the magnitude of the standard deviation (σ , s). We have found that two standard deviations above and below the mean has provided good problem identification. These upper and lower bounds are referred to as the upper and lower control limits (UCL & LCL, respectively). The standard placement of the UCL and LCL in manufacturing is three sigmas above and below the mean. There are various methods of developing control charts.

C. R (range)charts

These charts monitor the range of a set of data that has been divided into subgroups. The points on the graph indicate the range (highest minus lowest) of the values in the defined subgroup. These control charts are best used when the subgroup size is small (usually less than 25 data points)

D. S (standard deviation) charts

S charts are much like the R charts with the exception that the monitored parameter is the standard deviation of the subgroup verses the range. S charts have a better statistical accuracy than R charts.

E. MA (moving average) charts

MA charts represent the moving average of the sample averages. A span is determined for the chart which represents the frequency of the moving average. For instance if a span of 3 is used the first data point on the chart represents the mean of the first 3 subgroups and the next data point represents the mean of subgroups 2 through 4 and so on. Moving average charts are not as sensitive as cusum charts (see below) however they are good for reducing natural variability and identification of process trends.

F. MR (moving range) charts

The MR chart is similar to the MA chart except that it is the range of the subgroups that is monitored. The data points on the MR chart represent the range of values for the observations within the span

G. 2 Sigma analysis

An alternative to visually producing and reviewing charts would be to calculate the number of standard deviations (sigmas) that a point deviates by and list only those with an absolute value that is greater than two. The benefits of the limits set by the data is that instrument inaccuracy is not as important as sensitivity and repeatability. Using the limit of two standard deviations will give a 95 % confidence that any point outside that limit will be a true problem. Of course this means that 5% of the time the data will fall outside the limits and still be due to natural variation.

When using the 2 sigma analysis most problems identified will be valid. Wild goose chases, that are so prevalent when data is not dealt with in as rigorous

a fashion, are less frequent. Engineering staff concentrates on real problems, not imagined ones. As long as the process is steady, then the 2 sigma will work very well to pick up sudden changes in the process, however, there are a couple of disadvantages with using the 2 sigma method. One is when something happens which can affect many points in the process. For instance, when taking a condensate pump out of service (a known event) many points are affected and will exceed the 2 sigma limit. This introduces some noise to the process which must be dealt with. Another disadvantage is that slow trends will not be detected by this method if they are slow enough to shift the mean of the data. 2 Sigma analysis is best used in conjunction with other control charts which can compensate for these problems. The big advantage of using the 2 Sigma method, is that a large quantity of data can be looked at very quickly and easily.

H. Histograms

This chart is great for determining the characteristics of your data. For instance, it may be helpful to identify if data scatter is normal or skewed. Skewed data may identify an intervening process or system limitations. If there are multiple peaks, then a mean shift may be identified (instrument calibration among other things will cause this). Histograms can also be used to determine system capabilities (is the instrumentation or its placement adequate?).

I. CUSUM Charts

CUSUM is short for cumulative summation. The name attempts to give insight into the methodology employed. This may be the most difficult chart to understand, yet the most useful SPC tool. It is used to detect small mean shifts that may go undetected by the methods mentioned above.

1. Decision interval cusum

Associated with every data set is a mean value (m) and a standard deviation (s). If a point were to fall directly on the mean, it would be 0 standard deviations away from the mean. The value for z (number of standard deviations from the mean) then is zero (0). If a point were +1.5 standard deviations away from the mean the z value then is 1.5. Now, if a small *mean shift* occurs, it would be expected that subsequent values would stay, predominantly, either above or below the mean. Thus, the cumulative summation of z values above a preset sensitivity (usually 0.5 for 1 standard deviation) would indicate a mean shift. If two parameters (CUSUM parameters) were used to track the absolute values of the cumulative summations (of the z values), one for deviations above the mean and the other for those below, then when these parameters violate a preset limit (typically 4) a true mean shift would be detected. It is also important to know that these CUSUM parameters have a lower limit of 0, in other words, they can never go negative.

2. Vmask cusum

Another way to represent the cumulative summation is on a control chart which defines its limits via a "Vmask". The CUSUM in this case is still the continuous summation of the residuals from a given target. This is expressed as the cumulative sum of the difference of a subgroup average from a target mean. Since the cusum gives equal weighting to historical as well as current data; the cumulative deviations can be represented on one graph. In this method, the cusum statistic can be negative or positive. If any of the points fall outside the Vmask, the entire process is considered to be out of control.

VI. Bringing the process into control

This is probably the most difficult and the most important part of SPC. In order to use SPC methods, the data must first be brought to a point where as many as possible of the known variables are either removed or corrected for. For instance, we know that in a Nuclear Power Plant the thermal input to the cycle is relatively constant. One parameter that can vary is the temperature of the primary coolant. Altering this temperature at a constant thermal power level can cause steam generator pressure to vary. This varying pressure will correspondingly change the relationship between the volumetric and the mass flow through the turbine, and hence, first stage pressure will change due to control valve throttling. When tracking first stage pressure as a performance parameter these affects due to steam pressure should be removed. Computer Models can help in developing these equations. The model will provide the necessary information concerning the relationship and then a polynomial can be used to correct the first stage pressure. Of course this all hinges on the quality of the computer model. In all cases the correction curves should be analyzed to ensure that what is happening in the plant is what is reflected in the corrections. Another possible method is, that if a unit is in relatively good condition, to have the operators change various parameters, and use the empirical data from these tests to develop the correction curves. Many of the necessary corrections can be developed from relationships that are already known or supplied by the thermal kit; such as the relationship between condenser backpressure and design heatrate. Much care must be taken to make sure that the correction curves do not mask problems. Even after the curves are developed and applied to SPC a continual sanity check must be performed. Various plants have various amounts and control of their instrumentation. The instrumentation used to monitor plant performance should be evaluated to insure that they are producing reliable indications. What instrumentation is available will also determine what kind of corrections will be possible and what parameters are to be monitored.

In order to bring particular data point into control, assumptions must be made and understood even after the corrections are made. Some corrections made

could mask problems. The engineer who evaluates this data should be aware that this could be a problem. The best way to deal with this situation is to have various performance indicators. Each indicator corrects for different variables and in your evaluation the performance indicators can be used to play off each other.

VII. Program Scope

A. Performance Indicators (PIs) used at Peach Bottom:

(The Performance Indicators will naturally be in control)

1. Heat Rate {PI = HR actual corr - HR expected, Btu/kW-hr}
Gross indicator of cycle inefficiencies. Corrected for backpressure.
2. Station Use {PI = Auxiliary MW, MWe}
Identifies changes in plant configurations.
3. Flow Mismatch {PI = Wfw - Wsteam, MWe}
Identifies main steam system demand changes (bypass valve and other such leaks, service demands, et al).
4. Overall Turbine {PI = MWe actual corr - MWe P1, MWe}
Identifies losses within the turbine system.
5. LP Turbine {PI = 0.65 (MWe actual corr - MWe P6), MWe}
Identifies losses within the low pressure turbine system.
6. Condenser {PI = MW Pb exp - MW Pb act, MWe}
Identifies fouling/plugging, scavenging air problems, off-gas problems, air blanketing.
7. Condenser Heat Load {PI = f(MWth) , MWe}
Identifies the changes in thermal inputs to the condenser (e.g. bypass valve leaks, steam seal header RV leaks).
8. FW Heating {PI = Wfw (hfw exp - hfw act)/3, MWe}
Identifies problems with extraction steam, heater fouling, heater venting, heater level control problems, dump valve operation.
9. Overall Generation {PI = MWe expected - MWe actual corr, MWe}
Gross indication of cycle inefficiencies.

B. 2 sigma analysis at Palo Verde

Data is entered into a spread sheet program and most of the calculations required are performed in the spreadsheet. Approximately 400 points are monitored and another 100 calculations are performed. The results of the 2 sigma equations are displayed after the data. If any of these results are nega-

tive then those corresponding data points have varied more than two times the standard deviation. This can be used as a gross check of a large number of plant parameters yielding the few that may be problem areas. This saves a lot of time trying to find out which data points have varied significantly. Since the limits are based on the instrument variability you are only looking at changes that are not normal to that particular instrument. Only 100% power data is entered into the spread sheet so the variability due to power changes is not included in the data averaging and standard deviations. Since with this method a large number of data points can be evaluated, some problems can be found very quickly without a lot of head scratching or guessing. For instance high Feed Water heater DCA's do not have a great affect on a units heat rate, but if left unattended, damage to the drain cooler section of the heater can result and heat rate affected in a very noticeable way. With this 2 sigma method the day a DCA on any of the Feed Water heaters varies more than the limit, it can be picked up on immediately and corrected. Extraction pressure changes due to a high level dump opening is another example of how the 2 sigma will allow quick notification of a problem. Temperature changes throughout the cycle due to operating conditions have been detected, and after speaking with the operators, have been corrected. Using the 2 sigma method with the spread sheet allows immediate graphing of problem parameters, and ready access to the rest of the plant data.

In order for the 2 sigma method to work effectively the data must be filtered. For instance, data is only entered into the spread sheet when the plant is greater than 99.8 % power. Every operating station will have to determine what these filters are. Some plants operate at a lower power level; some plants power level may vary more than other plants. In any case the conditions of each operating unit will have to be considered. Corrections to the data may have to be made before it can be considered in the 2 sigma equation. As engineers, sometimes we are reluctant to take data out of consideration but it is sometimes required. Its kind of like thinning out a garden patch. If the plants are left crowded together you get a lot of plants with inadequate yields. If you don't "thin out" your data you end up with a lot of data with inconclusive results.

There are times when the plant will be operating in an unusual condition for an extended period of time. In this case the data can be trended and the 2 sigmas applied. When the plant returns to normal an evaluation will have to be made as to whether to start over with a new set of data. There are certain conditions which you will have to live with. For instance, when the weather changes drastically. In Arizona, the weather patterns often cause the wet bulb temperature to vary from 45 Deg F to 75 Deg F in a matter of days. Since we use forced draft cooling towers, this will cause many of 2 sigmas to be exceeded until there is enough data to change the standard deviation or the mean. There are different ways to deal with these kind of problems. If it is

something you know is going to happen, intelligence can be written into the equations to trigger another set of equations to be used, which will allow for the variance in the data when circulating water temperature changes by a certain amount. There is always a danger when doing this kind of manipulation of missing something. At this time we just live with the 2 sigma violations as long as we can explain the reason for them. Even with computer help, diligence is warranted to make sure that something is not getting lost in what you think is just a wet bulb temperature change.

VIII. Summary

Deployment SPC is not the "end all" in plant performance monitoring. We would submit that a good plant performance program requires three strong elements. First and foremost, a performance engineer is required. This person needs to be highly qualified and motivated. He needs to have strong system and component knowledge. Another element is a SPC based performance monitoring program for identifying deviations in crucial plant parameters. Last but not least, a well written "What-if" model that can accurately identify the effects of various cycle changes. With this the effects of deviations that are identified may be quantified. For example, how much will the plant output change if a dump valve on the moisture separator is leaking 10,000 lbm/hr? The calculation is not as straight forward as it may seem. It requires iterative analysis to zero in on the impact. Things like feedwater heating effect due to loss of drain input, turbine effect due to replacement of the drain input heating with steam, etc. These models are commercially available from a variety of vendors. All are based on strong empirical and theoretical foundations; GE paper 6020, HEI documents, etc.

SPC methods are not a panacea for solving all performance problems. They are very useful in the identification piece of the entire program; i.e. what is important or significant and what is not. Both the performance monitoring programs at Peach Bottom and Palo Verde have benefitted from applying statistical principles and techniques, with an overall result of people dealing with data in a far more consistent, open and educated way. We encourage you to take the step and enjoy the benefits.

IX. Appendix A: Statistical Definitions

These definitions are given for the sake of clarity. If the reader is already familiar with basic statistical terms please skip this section.

A. Measures of Central Tendency

1. Mean:

The arithmetic average of the data:

$$\frac{\sum_i x_i}{N} = \bar{x}$$

2. Median:

The middle number in an ordered set of numbers; if there are an odd number of observations it is the middle number ; if there are an even number of observations the median is half way between the two middle numbers.

P_{50} : The Value that has 50% of the data less than or equal to it.

Example 1: ---14,18,20,29,55,69,450

$P_{50} = 29$

Example 2: ---14,18,20,29,55,69

$P_{50} = (20+29)/2 = 24.5$

B. Measures of dispersion

1. Variance:

The sum of the squares of the deviation from the mean divided by one less than the total number of deviations from the mean:

$$\frac{\sum_i (x_i - \bar{x})^2}{N - 1} = s^2$$

2. Standard Deviation:

The square root of the variance.

$$\sqrt{\frac{\sum_i (x_i - \bar{x})^2}{N - 1}} = s$$

3. Range:

The difference between the highest and lowest values in a population sample.

4. Normal Distribution:

A sample is normally distributed when all the variances are due to random causes. The normal distribution is the famous bell curve, developed by Gauss to describe the distribution of measurement errors. This curve is the result of a histogram of a sample in which all the variances are due to random causes. Remember that the curve does not have to exactly match a bell curve to be normal. What is more important is that the histogram has the general shape of a bell.

The calculation of control limits along with the use of control charts presupposes that the data is normally distributed. There are other methods for calculating control limits on data that is not normally distributed. It is very important that you know if your data is normally distributed before you apply SPC methods. The use of Histograms will aid in the determination of a normal distribution.

C. 2 Sigma Equation

The 2 sigma Equation is really a "2 s" equation since for a population sample the "s" term is used instead of the "σ". 2 sigma has been historically used as the indicator for Palo Verde.

$$\left(2 \times \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{N - 1}} \right) - \left| \sum_i x_i - x \right| = 2\sigma$$

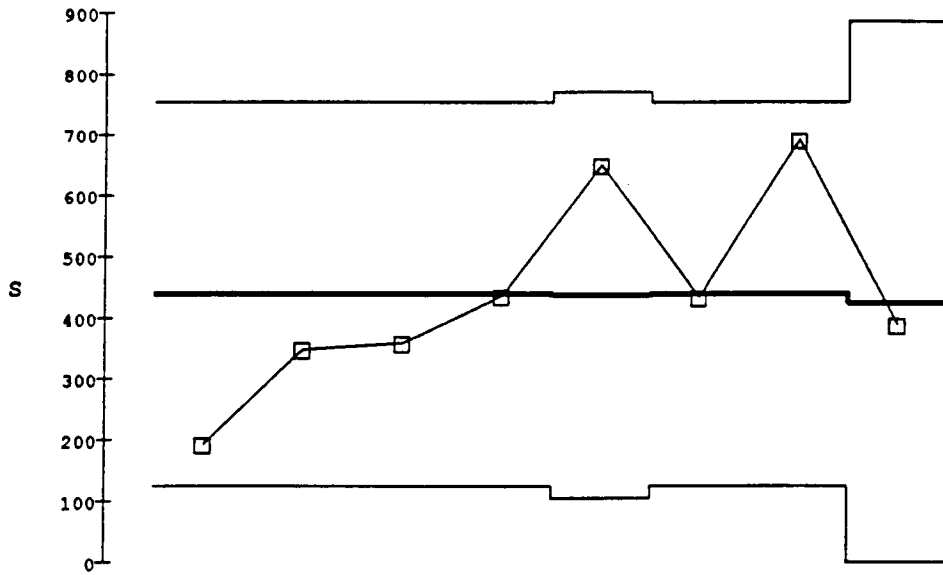
X. Appendix B: Examples of Control charts

On the following pages are some examples of various control charts. These charts are made from data at Palo Verde: Unit 3 Cycle 4 combined drain and condensate flow.

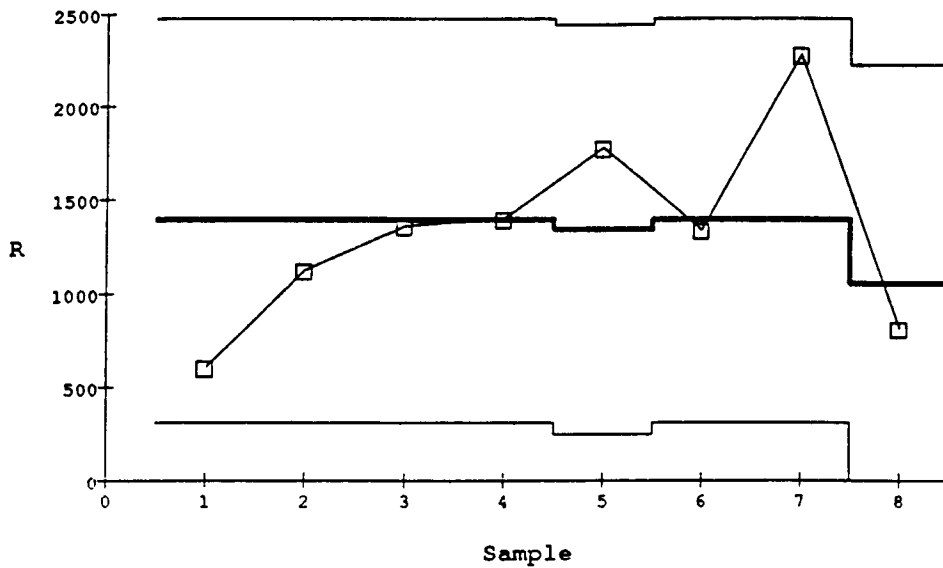
S (standard deviation) and R (range) charts

Data table: MARCH31 Column: DRN/COND FLW

S Chart



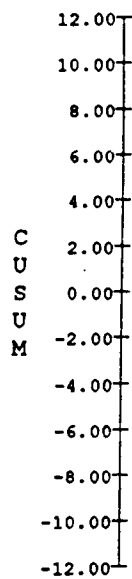
R Chart



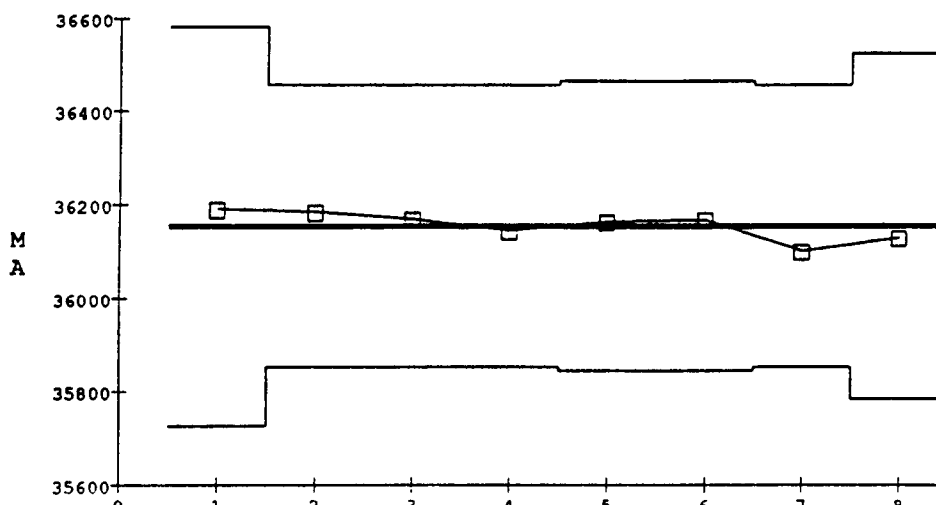
CUSUM and MA (moving average) charts

Data table: MARCH31 Column: DRN/COND FLW

CUSUM Chart



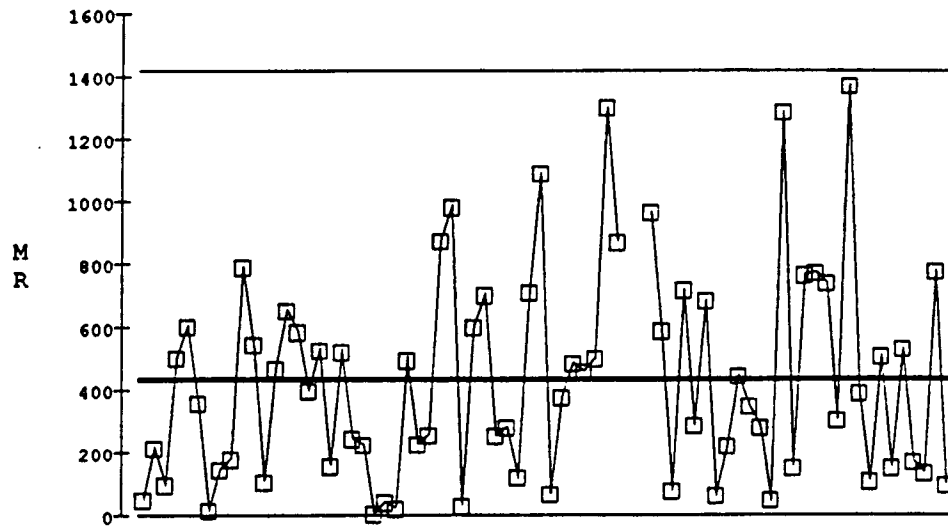
MA Chart



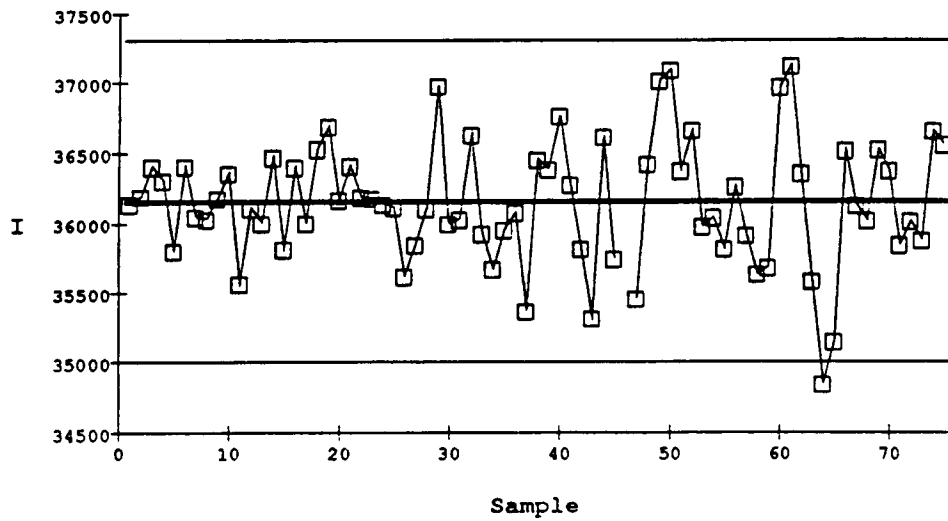
MR (moving range) and I (individuals) charts.

Data table: MARCH31 Column: DRN/COND FLW

MR Chart



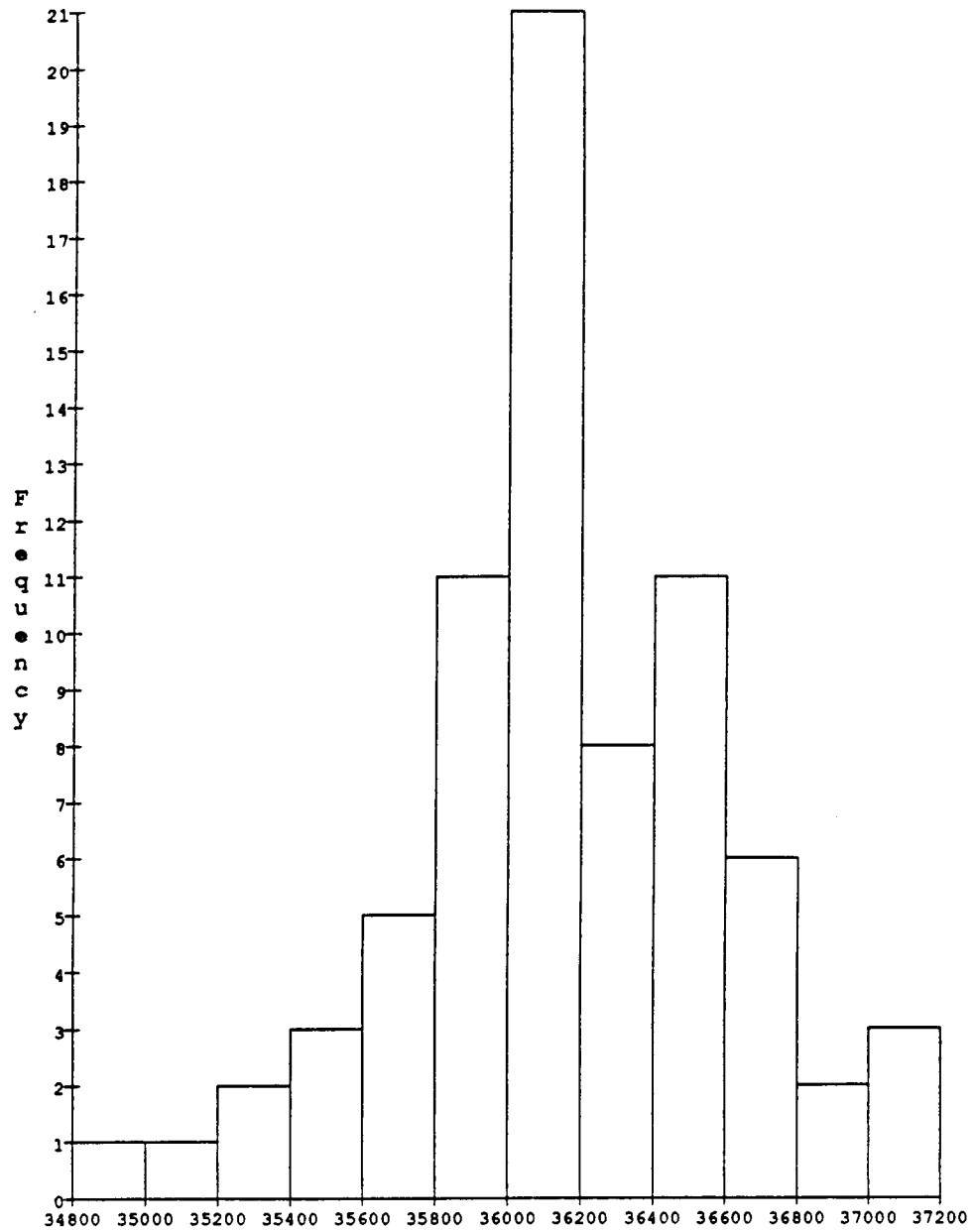
I Chart



Histogram

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XI. Bibliography

- A. "Out of the Crisis" W. Edwards Deming, Massachusetts Institute of Technology,1991**
- B. "Handbook of Statistical Methods for Engineers and Scientists", Harrison M. Wadsworth, Jr. , McGraw-Hill, 1989**
- C. "Statistical Process Control Manual (version 1.1),SSI Management Consultants, Inc. 24803 Detroit Road Westlake, Ohio 44145, 1990**
- D. "Statistical Methods For Quality Improvement", Thomas P. Ryan, John Wiley & Sons,1989**
- E. "Statistical Process Control (Overview)", W.R.Brooks & F.G. Dunbrack, Presented to Canadian University Counsel on Advanced Ceramics,1988**