Process Safety Valves
H. Paul Barringer, PE
Barringer & Associates, Inc.
Humble, Texas
hpaul@barringer1.com
Phone 1-281-852-6810

Process safety valves (PSVs) protect against over pressure conditions. Periodic inspections are required for these safety devices to verify compliance with industry codes such as ASME and API standards. PSVs also have a business purpose for controlling financial risks. PSVs are clearly not a run to failure strategy. PSV strategy must be based on reliability which requires periodical testing to verify results comply with established standards. PSV strategy is clear: Show me with independent tests, don’t tell me all is well!

Process safety is different than personal or occupational safety as defined in the Baker Report1. “Personal or occupational safety hazards give rise to incidents—such as slips, falls, and vehicle accidents—that primarily affect one individual worker for each occurrence.

Process safety hazards can give rise to major accidents involving the release of potentially dangerous materials, the release of energy (such as fires and explosions), or both. Process safety incidents can have catastrophic effects and can result in multiple injuries and fatalities, as well as substantial economic, property, and environmental damage. Process safety refinery incidents can affect workers inside the refinery and members of the public who reside nearby. Process safety in a refinery involves the prevention of leaks, spills, equipment malfunctions, over-pressures, excessive temperatures, corrosion, metal fatigue, and similar conditions. Process safety programs focus on the design and engineering of facilities, hazard assessments, management of change, inspection, testing, and maintenance of equipment, effective alarms, effective process control, procedures, training of personnel, and human factors. The Texas City tragedy in March 2005 was a process safety accident.”

The Baker Report on the following page says: “In making its findings and recommendations, the Panel’s objective was excellence in process safety performance, not legal compliance.”

While definitions in the Baker report specifically refer to refineries, only the naïve will believe the concepts apply only to refineries. Process safety hazards apply to your business. Don’t get caught in the failure to learn2 cross fire. You must take action to solve problems and reduce risks. Don’t be seduced by the never ending struggle to make money. Process safety is more about doing the right things to stay out of jail, to stay out of lawsuits, to stay out of court, to stay out of fines, and to live with your conscience of doing the right things to avoid process safety failures. You never have to apologies for doing the right thing. You will have to beg forgiveness for doing the wrong thing! When the process safety train jumps the track and your name is attached to the tragedy you will go into the grave with the burden of insufficient action that causes great harm along with loss of respect from family, friends, colleague’s, and shame against your name. Do the right thing now for process safety and PSVs are a good starting point to verify they pop at the set pressure which is straight forward to test but the desired flow rate is difficult to test and must be designed into the product!
Be realistic and take process safety plus personal safety approach to safety issues. Ask yourself: “Would you subject your mate, your children, and your mother to PSV risks that exist in operations under your control on a daily basis”? If the answer is yes, you have process safety in mind. If your answer is no to exposing your family to PSV risks, then you have problems that must be solved quickly and effectively.

We expect PSVs will always accurately function as designed. The reality is PSVs don’t always perform as planned. Inspection of these devices is necessary to learn what you don’t know about their compliance. PSVs must be inspected at regular intervals to quantify and control risks three ways:

1. Find probabilities of PSVs failing to open to relieve high pressures that could result in danger to people, equipment, environment, and loss of production processes. This is a high cost risk.
2. Find probabilities of PSVs opening early with product loss from the process and resulting pollution issues plus financial losses from unsaleable product. This is a lower cost risk.
3. Show the probability of verifying PSV integrity to honestly perform its intended function without “pencil whipping” (which is a dishonest act) test data…after all your own life may depend on reliably producing true and honest results. Honest data is an ethical requirement.

As with all safety devices you need test results before calamities occur. For example, testing fire escapes for blockage after the fire occurred and with loss of human life is of little value. Whereas testing fire escapes before potential fires occur is the sensible thing to do. As with all safety devices, testing is mandatory. Treat testing seriously—it is not a casual matter.

PSV non-compliance defines failure risks for popping open too early and too late to control $risks. The risk equation is: $risk = (probabilities of failure)*(consequence). It is prudent, for your long term employment, to keep the $risks within your allowed signature authority. Think of PSVs as a personal hazard for your own skin and as a process hazard with larger business issues.

There are three types of probabilities involved in PSV risks:

1) The overall probability of PSV failure, i.e., PSV non-compliance—the sum of the following,
2) The probability of incurring a high pressure event with dangerous loss of containment, and
3) The probability of incurring a low pressure event with economic losses of product.

Undetectable over pressure events on PSVs can have high $consequences of failure. Under pressure events of leaking PSVs opening too early are frequently detectable and usually have lower failure $consequences. Worry and take action with PSVs opening too late, i.e. high pressures—redundancy of PSVs can mitigate over pressure problems. Be concerned about PSVs opening to early, i.e., low pressures—detect low pop pressure leakage to prevent loss of product and contamination.

Want a fresh example of the need PSV redundancy it concerns a Japanese nuclear reactors rupture disk (rupture disks are also PSVs)? Tokyo Electric Power Co (TEPCO) investigators on May 19, 2015 reported a single rupture disk failed to open under high pressure. This now appears one failure root of the No. 2 reactor disaster at the Fukushima No. 1 Nuclear Power Plant during the March 2011 disaster. The disaster destroyed the reactor and shut down nuclear reactors in Japan from distrust in lack of reliability for Japanese nuclear reactors. The disaster spread nuclear contamination to earth and sea, and the contamination continues.
TEPCO has been investigating what went wrong with the venting systems in order to clear up the cause of the nuclear reactor disaster. The rupture disk which failed to relieve high pressure was located inside a pipe leading from the nuclear reactor’s containment vessel to an exhaust pipe. The rupture disk was meant to keep radiation from leaking outside. However, the disk was supposed to rupture after high pressure is applied to it. TEPCO’s continuing investigation found no evidence of radioactive pipe contamination downstream of the rupture disk, suggesting that the disk did not rupture, and the vented gas was trapped in front of it. Radioactive gas is thought to have leaked directly from the No. 2 reactor’s containment vessel, and it is estimated as having leaked the most radiation out of the No. 1 through 3 reactors. This is reported in the newspaper Mainichi, May 22, 2015 from Mainichi, Japan.

Does the Fukushima incident remind you of the old proverb:
  For want of a nail, the shoe was lost.
  For want of a shoe, the horse was lost.
  For want of a horse, a rider was lost.
  For want of a rider, the message was lost.
  For want of a message, the battle was lost.
  For want of a battle, the kingdom was lost.
  And all for the want of a horseshoe nail.

The moral of the old proverb is simple. Big problems often start with seeming small things but grow to huge disasters just has occurred with the Fukushima No 2 reactor from lack of rupture disk redundancy. Rupture disks should be tested to failure periodically just as with a PSV. Of course the rupture test is destructive, and the rupture disk must be replaced. Furthermore tests on rupture disk show great difficulty in complying with ±5% variation for non-ASME stamped RDs. However, ASME stamped RDs show good compliance.

PSV “simmering” with small, rapid, open/close is a common failure from operating pressures which are too high or less commonly failure of the PSV to stay closed as required. Generally speaking, pressure load roughness, i.e., large variability in pressure loads, shows greater variability than the smoothness, i.e., small variability, of relieving pressures, of pop pressure strengths of the PSVs. When pressure loads overlap the PSV pressure strengths a joint probability occurs for loads exceeding the strengths and mandatory popping of PSVs must occur to safely relieve high pressures. Simmering of PSVs is hard evidence that the “waves of process pressure” are coming over the “gunwale of our boats resistance to hold the pressure” and a release of pressure is eminent.

How can the probabilities be verified numerically rather than hypothetically? The preferred answer is:
  a) Build a load probability plot. Use maximum daily pressure loads for the load data.
  b) Build a PSV pop pressure probability plot from PSV test results for strength data.

Compute the interference zone where the distributions overlap by an Excel Monte Carlo simulation3 to find the probability of failure for high pressure conditions.
Figure 1 shows a Weibull probability plot of system load pressures on the left hand sloped line [beta = 31.7, eta = 6997.00 psi]. Pop set pressure is 7500 psi with ±3% tolerance (7275 to 7725 psi) as shown by the right hand sloped line [beta = 77.22, eta = 7606.00]. The plot was made with SuperSMITH probability software. In Figure 1, 99.98% of the system PSV load pressures will vary between 5233 to 7505 psi. Also 99.98% of PSV’s tests will pop between 6751 to 7828 psi. Thus we have a load strength interference problem where pressure loads are too high for the PSV strengths!

The probability of having a pressure load too high and PSV strength too low is a joint probability issue. Figure 2 solves for the interference area using calculus to shows a system reliability of 99.5191% with the joint probability interference area of 0.48087% (see http://www.barringer1.com/feb05prb.htm for the equations and the Excel spreadsheet for Monte Carlo simulations.
Figure 2: 0.48087% Probability Of Load-Strength Interference Resulting in PSV Failures

Figure 3 shows the unreliability calculations using Mathcad to solve the calculus problem.

Figure 3: Mathcad Calculus Unreliability Calculation

Not all engineers have MathCad to solve calculus problems. Most engineers do have Excel for Monte Carlo simulations where random loads and random strengths tell the probability for success and failure.
Excel Monte Carlo simulations with 100,000,000 iterations show 0.481% probability of load-strength interference. For this case it will be economic losses of product. Assume the release event will occur for 24 hours. Assume event costs will be $500,000. The $risk = pof*consequence = 0.0048087*$500,000 = $2,404. Ask is this magnitude of loss within your signature authority. Another good test is would you pay out of you own pocket for taking this risk? Expect 3.66% of the PSVs will pop before reaching the lower pop limit of 7725 psi (and 3.14% of the load pressures will exceed the allowed low limit of 7275 psi). In short we need wider separation between loads and relief pressures for smooth function of production systems without economic losses!

Production can control this overlap area by controlling the loads so they do not have so much scatter—notice the wide scatter in the pressure loads and the tight scatter in the PSVs pops! The practical production issue is can we make more money by operating with higher pressures to overcome the risk of losing $2,404 in a one year interval.

The typical freeboard, in this case, between typical pop pressures and typical system load pressure is 7606-6997 = 609 psi. Launching a boat on a placid lake with no freeboard (freeboard is the distance between the water line and the gunwale or weather deck) would be considered a foolish decision as you need separation between the water level and the boat gunwale! Of course if you launched the same boat into the North Sea with its turbulent waves, you need greater freeboard distance because of severe wave action than for a placid pond. The same logic applies to operating pressures and PSVs to achieve always safe operating conditions. The practical problem is this: simple financial greed for higher operating pressures overcomes good common sense for safe freeboard of PSVs and realization that safety risks are involved in the decision.

Controlling operating pressures so they rarely reach the high side pop pressures is a safe method for protection from the high risk of PSVs failing to pop on the high side. This is easier said than done as the natural tendency is to raise normal operating pressures higher and higher for economic production reasons without taking into consideration equipment strengths and variations in strength along with variations in the magnitude of the loads. Basic greed can get out of control as we begin to work toward the stupid side of the risk equation; this requires an always safe philosophy to control $ greed.

As engineers, it is our ethical duty to protect the public (and our employees and the environment) from harm! This obligation applies to licensed and unlicensed engineers so this is not a trivial decision. When PSVs pop open, a failure has occurred! Common sense says avoid these failures for safe operation. Pressure Relief/Safety Valves 101 provides guidance for the use of good common sense.

Because your highest pressures are less than the lower pressure relief does not represent an always safe condition. If only conditions occurred that should occur we would not have disasters. PSVs must be capable of handling the upper limits of the set pressures for events which occur even when the problems traditionally shouldn’t occur. Remember this is a pressure SAFETY valve! It must function when called upon for duty to protect humans, equipment, processes, environment, and the business. Humans and the process should be controlled to avoid going into the face of danger!
Why are tolerances around the set pressure relief pressure allowed to vary by, say, ±3%, ±5%, and ±10%? It’s all about the equation $\text{Risk} = (\text{probability of failures}) \times (\text{Consequence})$. Suppose the $\text{Consequence}$ of a high pressure excursion is potentially at $\$1,000,000$ per year. The $\text{Risk}$ will be:

- $0.03 \times 1,000,000 = 30,000$ for 3% over pressure variances,
- $0.05 \times 1,000,000 = 50,000$, for 5% over pressure variances, and
- $0.10 \times 1,000,000 = 100,000$ for 10% over pressure variances.

These risks are beyond the signature authority of most engineers and many managers. Thus pressure relief pop pressures must demonstrate tight pop pressures around the set pressures to manage financial risks. Furthermore the operating pressures must be controlled to avoid facing danger!

You may think the $\$1,000,000$ consequence to be unreasonable. Remember permanently disabling a human being for life in the work place will cost $\$15,000,000$ to $\$30,000,000$. Killing a human in the workplace will vary between $\$1,000,000$ and $\$5,000,000$. Don’t misread these numbers and misbelieve that I’m arguing for the safety department members to carry side arms for administering coup de grâce to injured people! I am arguing for avoiding failures that damage humans and property! If you disbelieve these figures you’re not reading newspapers about settlements of lawsuits! Consider recent proposals for General Motor’s recall accidents where the first proposal, administered by Kenneth Feinberg, is $\$1$ million for death plus spouses get $\$300,000$ and dependents get $\$300,000$ each$^5$.

How do you arrive at the $\text{Consequences}$? Think about the fines, the damages, the remediation, the lawyers that will be involved, the decline in the company’s stock price, the corrective actions required as a result of the consequences, modifications required to correct the problem and the future problems that result from the known incident, think about your job consequences for “allowing” the catastrophe, and the list goes on and on. Think like a business person rather than a technical nerd. Write down your number and circulate it within your organization—the world loves to be your critic and you’ll get many divergent opinions that need to be discussed to arrive at the most workable and most believable $\text{Consequence}$ number. In case your company does not allow you to reference to in house consequences, read and cite some old numbers in a paper delivered to API Pipeline session in 2001 at http://www.barringer1.com/pdf/Barringer-API-Pipeline-Paper.pdf on page 3 for $\text{Consequences}$.

Suppose you don’t know the “real” probability of failure number, look to your risk matrix. If you don’t have a risk matrix, build a working example through discussions for your facility to avoid delays and indecision. See risk matrix examples at http://www.barringer1.com/nov04prb_files/Risk-Matrix.pdf.

Suppose we don’t have Monte Carlo simulation capability and distributions of pressure loads or distributions of PSV strengths. Can we make any rough estimates of the risk from the attribute data of PSV pressure test data (ignoring system pressure load variation and PSV strengths)? The probability of the PSV failing to open at the high side limit of 7725 psi is 1.3% based on an attribute test (high side pop failures divided by test of all PSVs for this pressure range). So for a worst case condition use the 1.3% risk value rather than shrugging shoulders and saying “I don’t know”. Assuming zero or 100% probability of failure would be a biased decision per Nate Silver$^6$. Notice use of this conservative high side pop pressure will be about 3 times more risk than working with the joint probabilities of load-strengths. It’s better to err on the safe side than to claim ignorance from lack of data or lack of data analysis.
With a little more data we could find the probabilities by use of probability plots. Read from the pressure demand plot the probability for the demand reaching the pop pressure. Read from the probability plot for non-compliance at the actual high side PSV pop pressures. Then multiply the two probabilities to get a quick, conservative, estimate of the joint probability for a high pressure event. If the pressure demand never reaches the pop pressure limit of the PSV a high pressure event never occurs even if the PSV is totally non-compliant but you don’t want to allow this condition to occur. Seldom do we live in this fairly-tale land where only good things happen! We must prepare for the disasters for which a PSV prevents. Murphy, the saboteur, works 24/7/365. Murphy always lurks in the background for a non-planned disaster to ruin your reputation and create financial disasters!!

Maximum pressure demands on a PSV can have many different distributions but often have long tails toward lower pressures and short tailed distributions toward higher pressures. Whereas individual pop pressures have longer tails toward higher pressures and shorter tails toward lower pressures (when PSVs pop early, as early pops are removed from service, repaired, and replaced to prevent loss of product so they are driven by reducing economic losses—but high pressure pops are unknowns until tested to verify pop pressures).

Testing PSVs requires formal statements since $\text{risks are involved}$:

1. Specify a clear written criterion for failure and success for pop tests. Where practical, use liquid testing medium to reduce risks for the testing staff. Leak failure must not exceed “x” volume per minute. If gas medium is used leak bubbles must not exceed “y” bubbles/minute.

2. Follow written procedures for conducting the PSV pop test on PSVs in the as received condition. Disassembly, clean up, and renewal prior to test is not allowed. Where the PSV is contaminated with gasses/liquids dangerous to humans and the environment, special provisions must be instituted to prevent dangers to humans and the environment.

3. Trained technicians must follow the test procedure and record the data of conditions found by test and age of the PSV in service with a clear understanding of success and/or failure.

4. A firm disposition with a clear guide is required for repair/rework/disposal of unusable PSVs.

5. Trained technicians must periodically undergo random testing of unknown (but pretested) PSVs as a qualification vehicle for verifying the technician’s competency to continue testing PSVs based on results obtained from the unknown (but pretested) PSVs.

6. The trained technicians must record leaking PSVs as failure at the leak pressure rather than recording the PSV as leaking with no test pressure recorded when leaks occur.

7. The engineering staff must specify specific inspection intervals for each pressure class of PSVs but not to exceed “z” years.

8. Record actual pressures from calibrated pressure transducers for X-axis response along with acoustical emission transducers to separate simmer pressure noise and PSV release pressure noise on the Y-axis for a later time audit trail of inspection results. See Figure 4 below.

9. Choose PSVs for inspection by Monte Carlo selection so the selection is made randomly similar to the case described for heat exchanger tube selection mentioned at http://www.barringer1.com/download/Inspect.xls so PSVs are selected for inspection on a random and unbiased method versus a haphazard method.
How often should PSVs be inspected?—the answer is “it depends”. The answer can vary from months for high risks up to 10 years for low risks. The owner must decide the inspection interval in an intelligent and rational manner that is defensible for a high cost calamity. Consider what literally happens in high cost consequence issues such as with steam turbines. To open a steam turbine and remove the shaft exposes the turbine to handling damage so the tendency is to delay detailed inspections given no other indicator of trouble. Most insurance companies will say “If you want an insurance policy for the turbine, you will open it at least every 10 years—else with no inspections you get no insurance for the turbine!” So there is always a hard practical limit of not more than 10 years given a benign steam turbine environment.

Most PSVs do not work in a benign environment. This requires shorter intervals between inspections for more severe conditions. Inspections tell you what you do not know—its show me, don't tell me what you wish to hear. The Alberta standard AB-506 provides some detailed guidance for inspection intervals. The Alberta Canada Inspection & Servicing Requirements for In-Service Pressure Equipment, in Table 1: Maximum Through Inspection And Servicing Intervals gives maximum servicing intervals for PSVs, pressure relief values in years for three different grades of equipment (grade 1 is high duty and grade 3 is lower duty) with variations of 1 to 6 years. Now the problem is defining the meaning of high
duty which would include high pressures, high probabilities of failure, and high consequences which would include safety/pollution/violation of regulatory limits and other things you will worry about having your name in the paper as the parent of the disaster. This means you must manage:

1. **People**—protect humans from harm,
2. **Property**—protect equipment and facilities from harm,
3. **Environment**—protect the environment from harm,
4. **Business production and profits**—avoid failures to keep the money machine functioning while addressing risk management responsibilities for
   a. **Moral reasons**—failure proof systems to meet society’s requirements,
   b. **Legal reasons**—meet legal requirements regardless of costs or actual risk levels,
   c. **Financial reasons**—work for the lowest long term cost of ownership.
5. **Honesty**—reporting integrity is essential even when test news is unhappy; remember you may be the victim of dishonesty with personal physical damage and loss of employment.

Without mandatory hard guidelines, keep this in mind: higher consequences and higher failure rates require more frequent inspection to control Sconsequences. This requires parallel, redundant, PSVs, to improve reliability of pressure control devices to protect the system. This means life cycle costs and safety integrity levels are mandatory concerns described in a worked out example. For high risk and high consequence issues, common sense says inspect more frequently. Risk based inspection techniques advocate if the $risk are high you need to inspect more frequently to control the probability of failure. Keep the $risks under your personal signature limit for preserving your job and avoiding taking foolish risks. In short, make good business decisions.

How often you should inspect your own personal protective equipment (PPE)? PPE visual inspections are recommended daily because the time spent is small and the cost is small but you should not take risk with your own safety. The concept is wrapped up in John Ruston’s 1800’s adage stating the common law of business balance “It’s unwise to pay too much, but it’s foolish to spend too little”. There are two distinct approaches to inspection data:

1. **High reliability organizations (HROs)** demand functions without failure and all identified failures are small failures with little harm. HROs have many small failures but no large failures. They use the small lapses as data pointing to bad things happening that require diligences for unexpected events that can happen. They acknowledge the bad news is not going away. HROs track small failures, they resist oversimplification, they are sensitive to operations, they maintain capabilities for resilience, they take advantage of shifting locations of expertise, they respond to threats with flexibility rather than rigidity, they manage unexpected threats and bounce back stronger to tackle future challenges.

2. **Run to failure organizations (RTFs)** look the other way at failures both large and small. They deny problems. They avoid inspections which show deteriorations and pending failures. They ignore failure consequences. They make careful propaganda about the cleverness of their organizations, while expected disasters will arise. With the luck of new managerial assignments they hope disaster will not occur on their watch. They control costs by avoiding both inspections and collection of data. They fail to take expensive corrective actions on
problems which have accumulated with time and use.\textsuperscript{9,10} RTFs put up a charming face while deteriorations, occurring with time and use, are ignored or denied because they are inconvenient to acknowledge or pay for corrections. However, when the inevitable disasters occur, the management group looks for lower level scapegoats to blame individuals rather than the organization recognizing the rot within causing the disasters from inevitable entropy deteriorations—you can’t rewrite the laws of physics by pencil whipped decisions.

Often companies have pressure ranges which they treat with different criteria such as low, medium, or high, and very high pressure PSVs. Select the pressure ranges based on your local conditions such as:

- Low pressures span 0\textsuperscript{+} to 300 psi,
- Medium pressures span 301 to 1,000 psi,
- High pressures span 1,001 to 10,000 psi
- Very high pressures 10,001 and up

How can a large quantity of PSV test results for various ranges be viewed for common understanding?

1. Group PSVs into their appropriate pressure ranges as noted above which contain a wide range of different pressures so the group can be studied as a pressure range class.

2. For each pressure class calculate PSVs pop ratios = (pop pressure)/(set pressure) for each PSV. The pop ratio data will look like error data for many different pop pressures in a selected range. Plot the pop ratio test data on a normal probability plot. Test results will generally fall on a straight line except for non-conforming PSVs. Mark the X-axis on the probability paper with vertical lines at the upper and lower allowed tolerances for, say, a \pm 3\% allowed range, vertical lines would be set on the low pop ratio at 0.97 and on the high side at 1.03. Satisfactory test results inside the allowed range are shown in Figure 5 below.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Good PSV Test Data For \pm 3\% Limits With 98\% Conformance}
\end{figure}
Test results outside of the allowed ranges represent failures to the left and right of the allowed vertical range lines as shown in Figure 6 below.

Figure 6: Poor PSV Results For ±3% Range With 20 Tests Out Of Tolerance For 80% Conformance

3. Probability plots of pop ratios, where tails of the pop ratio data cut outside of the upper and lower pop tolerances tell about non-conformances. How well the data fits a straight trendline tells about the goodness of fit. Hopefully 50% of the data occurs at a pop ration = 1 for absence of bias in the test results. If the straight trendline crosses 50% at lower than 1.0 it tells about bias of the PSVs toward early pop release. If the trendline crosses 50% at greater than 1.0 for pop ratios, it tells about a bias toward higher PSV pop pressure. For good control the trendline should cross 50% within ¼ of the allowed ratios. See Figure 7 below.

4. Take action to adjust, scrap, or replace non-conforming PSVs as appropriate. The assignable cause needs to be confirmed for long term corrective action including some valves that need more frequently inspections and other valves where the inspection interval can be stretched. Identification of test results outside the allowed range includes badly performing PSVs, incorrect testing procedures, and non-conforming test technicians who lack competency for testing of these important safety devices. Paint non-conforming PSVs with yellow paint as a caution reminder with the next non-conforming resulting is scraping of the PSV for non-compliance on the repeat test.
5. Present PSV test results to management. Discuss risks and consequences as these important safety devices have practical $\text{risks plus political risks for safety and environmental failures.}$ Management needs to know non-conformance details summarized because the PSV score card is also management’s scorecard as well as your scorecard.

Figure 5 shows, on an attribute basis, two data points fail to conform to the limits. However a probability plot would shows the entire data set of 100 data points would be well with the $\pm 3\%$ tolerance lines.

Trendlines on probability plots tell different information than does attribute data. In this case grading performance by attribute nose counts shows poorer performance.

Figure 6’s flat/steep/flat trendlines tells of mixed modes of performance. This indicates batch problems. Batch problems arise for many reasons such as PSV manufacturing problems, misuse, abuse, unforeseen increases in service usage such as PSV simmer, wrong application for the PSV, and sticking PSVs from the process fluids/gasses along with other reasons.

Figure 7 shows the trendline for the data is displace to the left of the desired value of 1.0 at 50%. The displacement has consumed $\frac{1}{2}$ of the low side tolerance resulting in 87% conformance. Had the trendline been centered at 1.0 the conformance would have been acceptable. There are many roots to this problem such as non-calibrated test pressure instruments, valve technician errors, and so forth.
Summary
Test PSVs to control your $risks. Know the results and risks to avoid living in a fool’s paradise with major $consequences to be paid. Make life cycle costs calculations for deciding how many PSVs should be installed in parallel to control risks using standard reliability calculations. Dynamic inaction is not responsible corrective action. Take responsible corrective action on these safety devices before you have blood on your hands.

One last question of a personal note for you action: Household hot water heaters have been known to blow up from runaway heat sources. When is the last time you popped the pressure relief valve on your hot water heater to verify the PSV inside your house can perform its intendant function? A hint for you, most household hot water heaters PSVs have a lever to make it easy to verify it can move to relieve pressure. Test to know the results—you may be surprised at your test results.

References:
3. Load-Strength Interference, http://www.barringer1.com/feb05prb.htm, download a Monte Carlo Simulation for Excel
8. Safety Integrity Levels (SIL) Standards Are Appropriate For Many Reliability Issues http://www.barringer1.com/jul13prb.htm