PG&E

Final Report No. 11-048

Final Report

Effect of Rounded Inclusions on the Integrity of Submerged-Arc-Welded Seams

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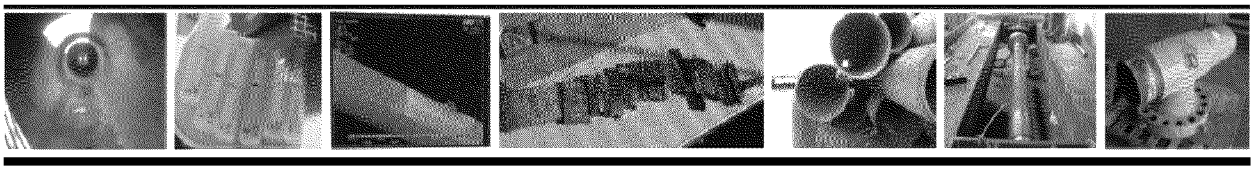
June 6, 2011



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Final Report No. 11-048

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on

EFFECT OF ROUNDED INCLUSIONS ON THE INTEGRITY OF SUBMERGED-ARC-WELDED SEAMS

to

PACIFIC GAS AND ELECTRIC COMPANY

June 6, 2011

by

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Kiefner and Associates, Inc.
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INTRODUCTION

PG&E plans to use radiographic inspection (RT) to ascertain the types of longitudinal seams in several of their existing pipelines. It is expected that in the process of these inspections, the presence of anomalies such as linear indications, porosity, and slag will be discovered from time to time. PG&E's pipeline integrity specialists intend to repair linear indications but believe that it is unnecessary to repair rounded indications, such as porosity and slag. In this document the evidence of the effects, if any, of rounded indications on the structural integrity of submerged-arc welds is examined.

SUMMARY AND CONCLUSIONS

Neither slag inclusions nor porosity are judged to be seriously injurious to weldments because of their generally rounded shapes. Both show up readily during radiographic inspections, and most welding standards consider slag inclusions and porosity to be non-injurious in limited amounts. The evidence discussed herein shows that these rounded anomalies can be expected to have little or no effect on the integrity of the submerged-arc seams in PG&E's pipelines. As a result it is recommended that if and when PG&E finds porosity or slag inclusions while radiographing submerged-arc seams in pipelines, repairs be made only if the following condition exists.

- The volume of porosity or slag inclusions or a combination of the two exceeds 5% of the volume of the weld metal along any given length of a submerged-arc seam.

BACKGROUND

Submerged-arc welds of the type used to make longitudinal seams in a common type of line pipe may contain discontinuities of various types. These include cracks in the weld metal and heat-affected zones, lack-of-fusion, lack-of penetration and porosity and slag. All of these kinds of defects may be found by radiographic inspection (RT) of the type PG&E is planning to use to determine whether the seam welds in some of their pipelines are single submerged-arc weld (SSAW) made from the outside of the pipe only or double submerged-arc welds (DSAW) made from both the inside and the outside of the pipe. Cracks, lack-of-fusion and lack-of-penetration tend to appear as linear indications in a radiograph. It is not easy to determine the depths of these linear discontinuities from the radiograph. Thus, it is not easy to judge the effects of such discontinuities on the strength of the pipe. Hence, PG&E intends to repair any linear discontinuities that are revealed in the radiographs. In contrast, porosity and slag inclusions are rounded discontinuities meaning that their size and distribution can be judged reasonably well from their appearance in a radiograph. When these kinds of discontinuities appear in a radiograph, PG&E intends to assess the extent of the discontinuity and repair only those which can be judged by size and distribution as possibly being injurious to the pipe.

DISCUSSION OF POROSITY

Porosity is defined by Lundin[i] as "cavity type discontinuities (voids) formed by gas entrapment during solidification." According to Lundin, the welding technical community has categorized porosity as Uniform Porosity (scattered throughout the weld more or less uniformly), Cluster Porosity (clusters of porosity separated by considerable lengths of porosity-free weld metal), Linear Porosity (occurs in a repetitious pattern along the weld), and Wormhole Porosity (elongated or tubular cavities caused by continuous entrapment of gas at the solidifying interface). Porosity may be totally embedded within the weld metal or it may be surface connected.

The term "Blowhole" is mentioned by Harrison (The Welding Institute) in Reference 2, but it appears to be associated with gas-shielded welding processes not submerged-arc welds.

Use of Radiography to Detect Porosity

Harrison[ii] states that "Radiography is the best NDT technique for detecting porosity…." Similarly, Lundin in Reference 1 states that "Porosity, being a volumetric type of discontinuity with rounded asperities, is most advantageously detected and evaluated by RT methods with regard to reference standards."

Criterion for Judging the Amounts of Porosity

Harrison states in Reference 2 that "…the percentage loss in cross-sectional area is the best parameter for assessing its (porosity's) effect on service performance." Cross-sectional area in this respect is determined by the quantity:

$$\text{[illegible]} \quad \frac{\text{[illegible]}\ \pi\ \%\ \pi\ \text{[illegible]}}{\text{[illegible]}}\ 100\ \text{[illegible]}$$

In the above equation, the pores are assumed to be spherical in shape. The volume of weld metal referred to is the area of weld metal represented on the radiographic image that circumscribe the pores times the wall thickness.

Harrison identifies two ways to determine the loss in cross-sectional area from a radiograph. One uses film density compared to a wedge-shaped calibration piece to obtain the volume of the pores. The other involves counting the pores of various sizes within a given area of weld metal and calculating the volume assuming the pores to be spherical. The area circumscribing the pores times the weld thickness is the reference volume, and the volume of porosity is expressed as a percent of the reference volume.

Effects of Porosity on Weld Integrity

The potential effects of porosity on the integrity of a weld could be a reduction in the strength of the weld or a reduction in the fatigue life. In Reference 2 Lundin states that many investigators have developed data that show that porosity levels on the order of 5% to 7% have no appreciable effect on the static strength of a weld. He further states that all investigators agree that the porosity levels of 2% to 3% have no effect on static strength. Most welding-code workmanship standards limit porosity of 0.5% to 1% by volume. So, clearly, porosity levels can exceed design standards and still have no deleterious effect on the strength of a weld. This is important for a fitness-for-service assessment of the type PG&E will be employing when weld discontinuities are revealed in the radiographs of the submerged-arc seams of certain pieces of pipe in existing PG&E pipelines.

In Reference 2 Harrison provides data from multiple investigators that show that porosity in amounts up to 7% have no effect on the tensile strength of welds.

Only one of the investigations was readily obtainable[iii] (a paper from the Department of Welding Engineering at Ohio State University). Reference 3 describes a research project in which specimens of AISI 1020 steel were joined by submerged-arc welds, and the specimens were subjected to inspection and mechanical tests to determine the effects of porosity on, among other things, tensile strength. The tensile tests were oriented such that the loading axis was transverse to the axis of the submerged-arc weld. The welds contained porosity with pore diameters ranging from 1/16 –inch to 1/8 – inch having the configuration of "wormhole" porosity (i.e., having a cylindrical shape with the axis of the wormhole being parallel to the axis of the weld). Several welds appear to have been made at different current levels to produce varying amounts of porosity. The tensile specimens were machined to final dimensions of 3/8- inch-width in the gage-length region by 3/8-inch-wall thickness with the weld reinforcement removed. Neither the exact number of specimens nor the individual results were given in the document. Three base metal specimens were tested to establish the benchmark tensile strength of the material. The authors state that "There is little change in tensile strength as the porosity increases to about 7% reduction of cross section." They also noted that the failures of the welded specimens with up to 7% reduction of cross section occurred not in the weld metal but in the base metal. The results can be interpreted as showing that there is no reduction in the tensile strength of the material due to the presence of the porosity. A factor in this behavior is that the weld metal's tensile strength consistently overmatched the strength of the base metal.

Harrison presents similar results from tests by other contemporary investigators including those by investigators at The Welding Institute and The Society of of Naval Architects of Japan. The results in all cases show no reduction in tensile strength with porosity in amounts up to 5% of the volume of the weld metal. The tests described in Reference 3 are particularly relevant to the situation of the PG&E pipe materials with submerged-arc seam welds. The materials and welds are similar, and the direction of loading in the tests is identical to the hoop stress in the pipe.

When it comes to the possible effect of porosity on fatigue life an important point about porosity is made in Reference 1. Unlike planar (crack-like) discontinuities which can grow readily in response to cycled loads, porosity is three-dimensional. Therefore, porosity involves a fatigue crack initiation process. Whereas, the behavior of planar discontinuities is characterized by crack propagation, discontinuities such as pores must undergo a crack-initiation phase before crack propagation can take place. Typically, crack initiation accounts for a much larger fraction of fatigue life (~90%) than crack propagation. Fatigue crack initiation is usually characterized in terms of applied stress, S, versus cycles to failure, N, commonly called an S versus N relationship or S-N curve. Harrison, in Reference 2, provided such S-N curves from a paper by Y. Ishii and K. Iida entitled "Low and intermediate cycle fatigue strength of butt-welds containing defects" (Journal of the Society of Non-Destructive Testing – Japan – Vol. 18, No 10, 1969 also known as IIW Document XIII-560-69). While one cannot know how many tests were conducted and what kinds of materials were studied without seeing the paper, Harrison summarizes the findings of the tests as follows. "Figure 3 (the S-N relationship) shows that, in load controlled tests, the fatigue strength for endurances up to 10^4 (10,000) cycles is nearly equal to the tensile strength (or the material) for porosity up to about 5%." Harrison also points out that the strength of the weld metal in this case (84,100 psi) undermatched the strength of the base metal (92,800 psi).

From the standpoint of low-cycle fatigue, the largest stress cycles to be expected in the pipelines operated by PG&E would be those associated with complete blow-downs and hydrostatic tests. PG& E specialists have stated that it can be expected that any given X52 pipeline likely would experience less than 10 such cycles over the life of the pipeline with a 52,000-psi (359-N/mm^2) stress range. As noted by Harrison the experimentally-developed S-N relationship shows that welds with 5% porosity could withstand more than 10,000 such cycles without a failure occurring. Hence, it would seem that porosity levels of 5% would not be of concern for the pipelines in the PG&E system from the standpoint of low-cycle fatigue.

When it comes to high-cycle fatigue, the operational pressure cycles to be expected in the pipelines operated by PG&E would likely involve stress ranges of less than 15% of the SMYS for the pipe. This has been confirmed by actual analyses of cycles. For X52 that range would be 7,800 psi (54-N/mm^2). The number of such cycles that could occur in one year likely would be less than 1,000. In Reference 2, Harrison presents S-N relationships containing data from several investigations for porosity ranging from 6% to 20%. The materials covered in these investigations were mostly high-strength steels such as HY-80 and HY 100. While the yield strengths of these materials are considerably higher than that of X52 pipe, it is known that their fatigue resistance is not any greater than that of X52 pipe. Therefore, the data presented by Harrison are relevant to the pipe in the PG& E pipelines. These data suggest that the seam welds in the PG&E system that might contain up to 6% porosity would be able to endure more than 10,000,000 cycles of the 7,800-psi range without developing fatigue failures, and that seam welds that might contain as much as 20% porosity could survive more than 150,000 cycles of the 7,800-psi stress range. Hence, it would seem that porosity levels of 5% or more would not be of concern for the pipelines in the PG&E system from the standpoint of high-cycle fatigue.

Some final points should be noted. References 1 and 2 both note that the test results are based on embedded porosity, whereas surface connected porosity is likely to have a greater deleterious effect than embedded porosity. Another point is that some of the work was done on plates of at least ½-inch thickness, and that porosity likely has a more deleterious effect on thinner materials or on materials where the crown of the weld has been ground off. These points are considered in the following recommendation.

Recommended Criterion for Repairing Seam Welds Containing Porosity

On the basis of the previous discussion, it is recommended that PG&E repair seam welds where the porosity is judged to be more than 5% of the volume of the weld metal.

DISCUSSION OF SLAG INCLUSIONS

In Reference 1 Lundin notes that "The terms 'slag inclusion' and 'entrapped slag' are commonly used to describe the oxides or other non-metallic, solid materials that are entrapped in weld metal or between weld metal and based metal." Lundin further notes that linear slag inclusions are continuous or intermittent lines of slag situated parallel to the axis of the weld while isolated slag inclusions have irregular shapes and are distributed within the weld.

Use of Radiography to Detect Slag Inclusions

In Reference 1 Lundin states that "Slag and solid inclusions are generally volumetric…" and "RT is especially sensitive to volumetric discontinuities such as porosity and entrapped slag.…"

Harrison[iv], in the context of noting that length is the parameter of interest relative to slag inclusions, states that "This (i.e., length as a characterizing parameter) has arisen from the use of radiography as the most common non-destructive testing technique for detecting and quantifying slag inclusions."

Criterion for Judging the Amounts of Slag Inclusions

Although slag is a volumetric discontinuity, it is usually rated in terms the lengths of the inclusions. In Reference 4 Harrison states that "It is almost universal practice in existing specifications to specify maximum allowable sizes of slag inclusions in terms of lengths of individual inclusions and also in terms of the summation of inclusion lengths in a given length of weld." He further states that "Although it is recognized that the through-thickness dimension of slag inclusions is, in theory, important, it is also believed that this dimension cannot vary widely. The length can be measured easily and seems to be a satisfactory parameter as far as the fatigue data are concerned. It is therefore proposed that length should be the characterizing parameter."

In Reference 4, Harrison suggests an interaction criterion to determine if two or more slag inclusions interact. If two slag inclusions are in close proximity, in terms of distances along the axis (l) and across the width of the weld (w), the "hypotenuse" $h = \sqrt{l^2 + w^2}$ should be used to determine whether or not interaction is likely to occur. Interaction is said to occur if h is less than $2.25t$ where t is the thickness of the weld or less than l_1 where l_1 is the length of the longer of the two inclusions. In that case the length of the inclusion should be taken as $l+l_1+l_2$. Where interaction is not indicated, the length of each individual inclusion is to be used.

Effects of Slag Inclusions on Weld Integrity

The potential effects of slag inclusions on the integrity of a weld could be a reduction in the strength of the weld or a reduction in the fatigue life. In spite of what Harrison states in Reference 4 regarding the importance of slag inclusion length, he presents data from two investigations that show that when considered on a volumetric basis, slag inclusions on the order of 5% to 10% have no appreciable effect on the static strength of a weld. Neither of these references was readily obtainable, but Harrison did provide a plot of the data. His plot shows tensile strength versus "defective area from radiograph." The data from one of the investigations is represented by a horizontal scatter band between 600 N/mm^2 (87,000 psi) and 700 N/mm^2 (101,500 psi) suggesting that the data were not particularly sensitive to the percent of slag in the cross section between 0% and 10% slag on the radiograph. The other set of data appears to show six tests, five of which represent specimens with slag percentages ranging from 0% to 2% that have tensile strengths of 470 N/mm^2 (68,100 psi) to 490 N/mm^2 (71,050 psi) and one with 10% slag that exhibits a tensile strength of about 420 N/mm^2 (60,900 psi). He further states that

"…slag inclusions, by their very nature, are unlikely to occupy a large proportion of the cross-sectional area and, therefore, we may conclude that the effect of slag inclusions on the static tensile strength in ductile materials is negligible."

Harrison's plot of the tensile strengths versus % slag does suggest that percentages less than 10 do not significantly degrade the tensile strengths of welds. There is no reason to suspect that this would not be true of the submerged-arc seam welds in the PG&E system. Therefore, it is rational not to repair such seams if they contain 5% or less slag.

Most welding-code workmanship standards permit slag inclusions up to a certain length. According to Lundin in Reference 1, most sections of the ASME code at the time WRC Bulletin 295 was written, permitted slag inclusions the lengths of which do not exceed 1/3*t* were *t* is the wall thickness or ¾ inch, whichever is less. So, slag inclusions up to a certain size are expected to have no deleterious effect on the strength of a weld. The data from Reference 4 showing that slag inclusions of 5% to 10% by volume appear to have no appreciable effect on tensile strength are important from a fitness-for-service standpoint. A fitness-for-service assessment is what PG&E will be employing when weld discontinuities are revealed in the radiographs of the submerged-arc seams of certain pieces of pipe in existing PG&E pipelines.

When it comes to the possible effect of slag inclusions on fatigue life an important point is made in Reference 1. Unlike planar discontinuities which can grow readily in response to cycle load, slag inclusions are three-dimensional therefore slag inclusions involve a fatigue crack initiation process. As mentioned in conjunction with porosity, fatigue crack initiation accounts for the majority of the fatigue life of a structure, with crack propagation occupying no more than about 10% of total fatigue life. Thus times to failure in the absence of crack-like defects are typically expressed in terms of S-N relationships.

As was noted in the discussion on porosity, the largest stress cycles to be expected in the pipelines operated by PG&E would be those associated with complete blow-downs and hydrostatic tests. In the worst case, any given X52 pipeline likely would experience less than 10 such cycles over the life of the pipeline with a 52,000-psi (359-N/mm^2) stress range. In Reference 4, Harrison presents an experimentally-developed stress-range-versus-cycles-to-failure (S-N) relationship which shows welds with slag inclusions as long as 15 mm (0.6 inch) could withstand more than 10,000 such cycles without a failure occurring. These data were generated by the same investigators in the same paper mentioned previously who looked at the effects of porosity on low-cycle fatigue strength of welds. Their tests of specimens containing slag inclusions show pretty much the same thing as did the tests involving porosity, namely, that thousands of large pressure cycles were required to cause the specimens to fail. Hence, it would seem that slag inclusions up to 0.6 inch would not be of concern for the pipelines in the PG&E system from the standpoint of low-cycle fatigue.

As was also noted in the discussion on porosity, the operational pressure cycles to be expected in the pipelines operated by PG&E would likely involve stress ranges of less than 15% of the SMYS or the pipe. For X52 that range would be 7,800 psi (54-N/mm^2). The number of such cycles that could occur in one year likely would be less than 1,000 as mentioned previously. In Reference 3, Harrison presents the results of high-cycle fatigue tests on shielded metal-arc welds (both cellulosic coated electrodes and low-hydrogen electrodes) that were done at The Welding Institute by himself and others. Several S-N relationships for slag inclusions ranging in length from 1.6 mm (0.06 inch) to continuous lengths of slag inclusions are presented. These data suggest that the seam welds in the PG&E system that might contain continuous slag inclusions would be able to endure more than 10,000,000 cycles of the 7.800-psi range without developing fatigue failures. Hence, it would seem that limited amounts of slag inclusions would not be of concern for the pipelines in the PG&E system from the standpoint of high-cycle fatigue.

Some final points should be noted. References 1 and 2 both note that the test results are based on embedded slag inclusions, whereas surface connected slag is likely to have a greater deleterious effect than embedded slag. Another point is that the work was done on plates of at least ½-inch thickness, and that slag likely has a more deleterious effect on thinner materials or on materials where the crown of the weld has been ground off. These points are considered in the following recommendation.

Recommended Criterion for Repairing Seam Welds Containing Slag Inclusions

On the basis of the previous discussion, it appears that the effect of slag inclusions on the tensile strength of a weld is related to the volumetric content of the inclusions, but their effect on fatigue life is controlled more or less by the lengths of inclusions and the applied stress range. The data seem to show that at small applied stress ranges typical of PG&E's pipeline operations, slag inclusions can be expected to have little or no effect on the fatigue life. Furthermore, it appears from the data presented in Reference 4 that the few number of large pressure cycles that can be expected from hydrostatic tests and complete blow-downs will not cause slag inclusions to fail by low-cycle fatigue crack growth. Therefore, it is recommended that PG&E repair seam welds where the slag inclusions, regardless of their lengths, are judged to be more than 5% of the volume of the weld metal.

UTILIZING THE RECOMMENDATIONS

Radiographs of the submerged-arc seam welds will be used to detect and characterize anomalies in the welds. As stated in the introduction, PG&E intends to repair welds with linear indications that are characterized as planar (i.e., crack-like). However, PG&E would like not to have to repair welds with small amounts of porosity or slag inclusions, and the data reviewed in this document suggest that 5% by volume of porosity and slag inclusions in terms of the weld metal volume can be safely left unrepaired. The process of determining whether or not the amounts of porosity and slag exceed 5% by volume needs to be defined on the basis of what is seen in a radiograph. That process is defined as follows.

First, the primary effect of a pore or a slag inclusion has to be its cross-sectional area on a plane perpendicular to the wall thickness because that area subtracts from the cross-sectional area of material that is expected to carry the hoop stress due to internal pressure in the pipe. Yet, the appearance of the pore or the slag inclusion in a radiograph is an area on an entirely different plane. The reasonable solution to this apparent dilemma is to assume that the anomaly is either spherical or cylindrical in shape, meaning that its area on the critical plane perpendicular to the wall thickness is the same as its area appearing in the radiograph.

Next, numerous pores or slag inclusions may exist within a certain length of weld. A means of accounting for an aggregate area of missing metal due to pores and slag inclusions is needed, and the critical cross-sectional area of material affected must be defined. Experience has shown[v] that fatigue cracks with lengths averaging 2 times the square root of the quantity diameter times wall thickness tend to develop at the toes of submerged-arc welds. This suggests the existence of a maximum length along the axis of a pipe over which interaction of small anomalies can begin to grow as a fatigue crack. For a 30-inch-OD, 0.3125-inch-wall pipe, the length $2\sqrt{Dt}$ is equal to just over 6 inches. Therefore, it seems reasonable to define the "reference area" as the measured wall thickness of the pipe times the length $2\sqrt{Dt}$ with which to compare the aggregate area of missing metal due to pores and slag inclusions. Using the measured pipe thickness ignores the reinforcement of the weld, giving a conservative estimate of the reference area. The parameter $2\sqrt{Dt}$ ranges from 6 inches for 24-inch-OD, 0.375-inch-wall pipe to 6.7 inches for 30-inch-OD, 0.375-inch-wall pipe (the range of the most common pipe sizes in PG&E's system), so using a reference area with 6-inch length times the measured wall thickness of the pipe seems reasonable. The 6-inch length should be considered a "sliding" length in the sense that the critical area will be determined by sliding the reference length along the weld until it encompasses the largest aggregate area of anomalies.

The area of a 1/32-inch pore is 6.25% of the area of a 1/8-inch pore, so it takes 16 (sixteen) 1/32-inch pores to have the same effect as 1 (one) 1/8-inch pore. So, it seems harmless to ignore the occasional pore that is less than 1/32-inch in diameter. However, the reviewer of the radiograph should use good judgment. If there are a lot of 1/32-inch pores, they will reduce the load carrying area. It is suggested that if 16 (sixteen) 1/32-inch pores occur within a distance of one pipe wall thickness, their area should be considered.

To accommodate the field application of these criteria, formal acceptance criteria have been developed by a PG&E NDT Specialist Level III. These criteria are presented in Appendix A of this document.

REFERENCES

[i] Lundin, C.D., "*Fundamentals of Weld Discontinuities and Their Significance*", Welding Research Council Bulletin 295, June, 1984

[ii] Harrison, J.D., "Basis for a Proposed Acceptance-Standard for Weld Defects, Part 1: Porosity", Metal Construction and British Welding Journal, Vol. 4, No. 3, March, 1972.

[iii] Green, W.L., Hamad, M.F., and McCauley, R.B., "The Effects of Porosity on Mild-Steel Welds", Welding Journal, Welding Research Supplement, Volume 23, No. 5, May, 1958, pp 206s-209s.

[iv] Harrison, J.D., "Basis for a Proposed Acceptance-Standard for Weld Defects, Part 2: Slag Inclusions", Metal Construction and British Welding Journal, Vol. 4, No. 7, July, 1972.

[v] Kiefner, J.F., Kolovich, C.E., Zelenak, P.A., and Wahjudi, T., "Estimating Fatigue Life for Pipeline Integrity Management", IPC04-0167, *Proceedings of IPC 2004 International Pipeline Conference*, Calgary, Alberta, Canada (October 4-8, 2004).

APPENDIX A

Alternative Acceptance Criteria for radiography of long seam welds in PG&E Gas Transmission pipeline assessments

These alternative acceptance criteria have been developed by Bob Scholes, an NDT Specialist Level III of PG&E's Applied Technology Services, on the basis of the document:

"Effect of Rounded Inclusions on the Integrity of Submerged-Arc-Welded Seams"
by John F. Kiefner, Ph.D., PE, dated June 6, 2011

All radiographic indications are to be initially assessed against the requirements of API 5L 44th Edition and documented on a radiographic reader sheet. Porosity and slag inclusions (defined either as linear indications in 1.a below or as rounded indications in 2.b. below) that exceed the requirements of API 5L shall be assessed by the PG&E NDE Level II technician using these alternative acceptance criteria, and the Indications Calculator spreadsheet prepared by Bob Scholes shall be used to determine the total cross sectional area (length of weld inspected i.e. 6 inches, multiplied by the measured wall thickness) and the actual cross sectional area of the indications so as to determine acceptance or rejection of indications.

Per the Kiefner document (referenced in Bold above), Rounded and Linear Indications (with the exception of those identified in "Acceptance Criterion 1") on Page 2 of this document, shall not exceed 5% of the affected cross sectional area of the worst 6” length of weld. The Indications Calculator spreadsheet shall be used to assess all welds with either rounded or linear indications.

DEFINITIONS:

1. Linear indications (other than those identified in Acceptance Criterion 1) on the following page shall:
    a. Be defined as having a length of three times its width or greater.
    b. Indications that are less than three times as long as they are wide shall be categorized as rounded indications.
    c. Aligned Linear Indications, separated by less than the longer of the aligned indications, shall be considered as one linear indication
2. Examination area:
    a. The examination area shall be a 6” long section of weld where discontinuities are found.
    b. The 6-inch-long examination area shall be positioned so as to include the greatest number of indications and/or those appearing to constitute the largest aggregate area of inclusions. Indications that extend outside of the 6” inspection window shall be considered (for cross sectional area considerations) as being within the 6” window.

ACCEPTANCE CRITERIA:

1. Any Cracks, Lack of Fusion and Lack of Penetration shall be rejected.
2. Linear indications:
    a. For linear indications other than those identified in Acceptance Criteria 1) above, the maximum allowable number of linear indications shall be 3 in any 6” length of weld, irrespective of their cross sectional area percentage.
    b. Linear indications for consideration in the Indications Calculator spreadsheet shall be individually identified and their length and width (cross sectional area as seen on a radiograph) entered into the spreadsheet.
3. Rounded indications:

a. All rounded indications shall be entered into the Indications Calculator spreadsheet. Rounded indications of 1/32” or less shall be categorized as 1/32”. The largest measured dimension shall be used, and the total number of individual rounded indications shall be entered into the spreadsheet.

b. Cluster porosity: The PG&E NDT Level II technician shall enter the individual size and numbers of pores into the Indications Calculator spreadsheet. Where this is not practical, the largest diameter of the cluster shall be entered into the spreadsheet.

    i. If the cluster has a length that is greater than its width, it shall be entered as a linear indication, irrespective of its length to width ratio.

    ii. Cluster porosity shall be separated from any other indication, either rounded or linear, by a minimum of 3 times the thickness

c. Rounded indications having a “density” higher than pores of a similar size in a similar thickness material shall be rejected as this is indicative of a non-round gas pore that may have a considerable through wall dimension