

Pipeline Research Council International, Inc.

EC-2-9

Peer Review of the Plausible Profile (Psqr)
Corrosion Assessment Model

Project Final Results

Presented By, RSI Pipeline Solutions

November 5, 2019



Peer Review of the Plausible Profile (Psqr) Corrosion Assessment Model - Overview

- **Background:** An enhanced corrosion assessment model (Psqr) has been developed by TC Energy (TC). The Psqr Model retains some of the fundamental aspects of RSTRENG but utilizes a novel approach to characterize the shape of the metal loss.
- **Research Objective:** To conduct a review by subject matter experts of TC's Psqr model for assessing corrosion.
- **Project Deliverable:** A report by the subject matter experts on the effectiveness of the Psqr model for predicting burst pressures of corrosion anomalies in a pipeline.
- **Principal investigator:** John Kiefner
- **PRCI Project Team Leader:** Shenwei Zhang

The Peer Review Team

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- **Maher Nessim**
C-FER Technologies
- **Ming Gao**
Blade Energy Partners
- **Ravi Krishnamurthy**
Blade Energy Partners
- **Phil Hopkins**
Independent Consultant
- **Andrew Cosham**
Ninth Planet Engineering
- **Michael Rosenfeld**
RSI Pipeline Solutions
- **Bruce Nestleroth**
Kiefner and Associates, Inc.
- **John Kiefner**
RSI Pipeline Solutions

The TC Team That Developed the Psqr Model

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- **Shahani Kariyawasam**
- **Shenwei Zhang**
- **Jason (Zijian) Yan**
- **Terry (Guoxiong) Huang**
- **Mohammad Al-Amin**
- **Erwin Gamboa**

Work Performed by the Reviewers

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- Reviewed TC Energy's Psqr Model.
- Carried out independent evaluations of the technology.
- Suggested modifications to the model leading to an "axial alignment factor".
- Reviewed the validating experiments.
- Requested additional validation of the model against public domain data.
- Requested that TC Energy provide more information on how the model works with ILI data, and why it provides enhanced safety.
- Produced a final report entitled "Peer Review of the Plausible Profile (Psqr) Corrosion Assessment Model" PRCI Catalog No. PR218-183607-R01. September 19, 2019.

Need for a Better Model

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- Like many pipeline operators, TC has used RSTRENG to calculate failure pressures of corrosion-caused metal loss anomalies based on ILI-provided dimensions in order to repair those anomalies which could adversely impact pipeline integrity.
- As TC and other operators have frequently observed based on direct examination of the pipe after excavation, the pits that lie along the “river-bottom” (worst-case) metal loss region often are displaced circumferentially from one another to such an extent that they do not fully interact. As a result, an RSTRENG calculation based on a projection of the river-bottom pit depths to a single longitudinal profile often under-predicts the failure pressure of the anomaly. When this happens repeatedly with ILI-provided dimensions, an operator ends up excavating significant numbers of anomalies that do not need to be repaired. These unnecessary excavations do not lead to enhanced safety. They simply add to the cost of managing pipeline integrity without adding any benefits.
- TC set out to develop a better model that would reduce the number of unnecessary excavations.

How the New Model Works

- TC's new approach involves calculating multiple failure pressures each based on a "plausible profile". Hence the model was named the Plausible Profiles (Psqr) Model.
- TC uses a statistical process for creating each plausible profile.
- The failure pressure for each plausible profile is calculated using RSTRENG.
- The analysis of multiple plausible profiles results in a statistical distribution of failure pressures all of which are greater than or equal to the one based on the RSTRENG river-bottom profile.
- Based on validating burst tests of 30 corroded pipe samples, TC chose the lower 5th percentile value of the distribution as the failure pressure of the anomaly.
- The TC team has developed a Microsoft Excel, VBA-based computer program and user's guide for the execution of Psqr calculations. The user's guide is presented in Appendix G of TC's report. This program will be deployed to the PRCI members as part of the deliverables of Project EC-2-9.

Psqr is Similar to RTRENG in Many Respects

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- **Applicable to all grades of pipe ranging from Grade A through Grade X100**
- **Applicable to all diameters and wall thicknesses**
- **Not applicable to brittle fracture initiation**
- **Not applicable to selective corrosion in an ERW seam**
- **Not applicable to corrosion in a dent**
- **Not applicable to corrosion where the maximum pit depth exceeds 80% of the wall thickness**
- **Not applicable to circumferentially-oriented grooving such as adjacent to a girth weld**
- **May provide less accurate predictions of failure pressure for metal loss in a pipeline subjected to extreme axial loading**

How is Psqr Superior to RSTRENG?

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- **170 corrosion features with laser scan field measurements.**
- **44 of the 170 features would have required repairs based on RSTRENG whereas only 5 of the 170 (89% fewer) would have required repairs based on the Psqr Model.**
- **154 immediate features reported by an MFL tool vendor using RSTRENG**
- **For the 154 immediate repairs that would have required excavation based on ILI data assessment using RSTRENG, only 31 (80% fewer) would have required excavation based on the Psqr Model.**
- **A subset of 84 features from the 154 immediate features where both the ILI data and the laser scan field measurements were available for comparison.**
- **Only 15 would have been excavated if the Psqr Model had been used. All 84 would have been excavated based on RSTRENG calculations.**

TC's 30 Validating Burst Tests

Parameter	Range
Diameters	8.625 to 48 inches (219.1 to 1219.2 mm)
Wall Thicknesses	0.181 to 0.563 inch (4.6 to 14.3 mm)
Grades	X52 and X70
Max. Pit Depths	30% of WT to 97% of WT
Lengths of Corrosion	11.9 to 170.3 inches (303 to 4326 mm)
Actual Corrosion	16 tests
Machined and Etched Features	14 tests
Failure Stresses	107.0 to 146.1 % of SMYS

Accuracy of Psqr Compared to RSTRENG Based on 30 Burst Tests

Statistic	Ratio of Actual to Predicted Failure Pressure	
	Psqr	RSTRENG
Maximum	1.25	1.52
Minimum	0.99	1.10
Mean	1.131	1.309
Std. Dev.	0.066	0.104

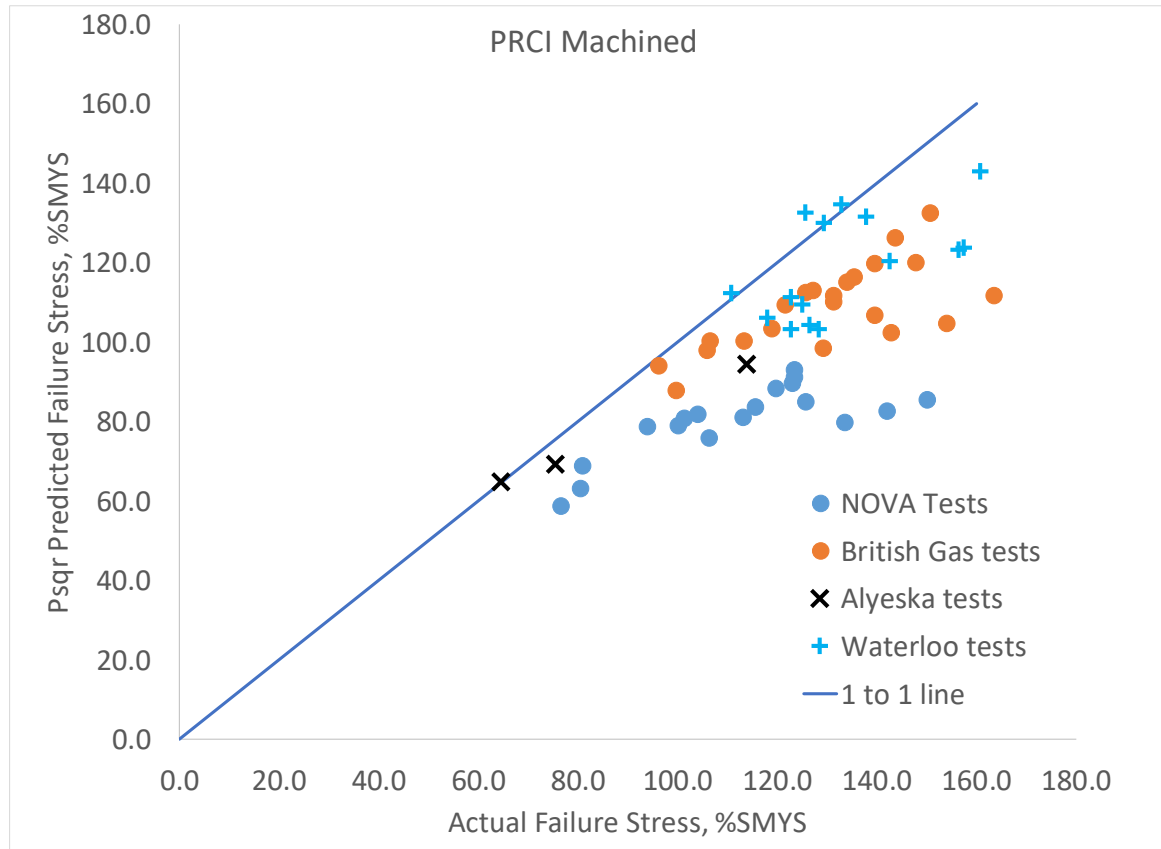
The Axial Alignment Factor

- Psqr Model software calculates an “axial alignment factor” (AAF) in addition to the plausible profiles calculations over the rectangular area that inscribes the entire corrosion anomaly.
- The software analyzes areas of the anomaly having widths equal to six times the wall thickness of the pipe ($6t$) and lengths equal to the total length (L) of the anomaly, one at a time, starting at one circumferential extreme of the anomaly and moving one gird space circumferentially for each calculation until the entire width of the anomaly has been traversed.
- The ratio of the RSTRENG-predicted failure pressure for each $6t \cdot L$ strip is compared to the RSTRENG-predicted failure pressure for the whole anomaly.
- The AAF for the whole anomaly is defined as the minimum of all such ratios.
- If the AAF is greater than 1, the Psqr Model 5th percentile value is taken as the predicted failure pressure of the anomaly.
- If the AAF is equal to 1, the RSTRENG-predicted failure pressure for the whole anomaly is taken as the predicted failure pressure of the anomaly.

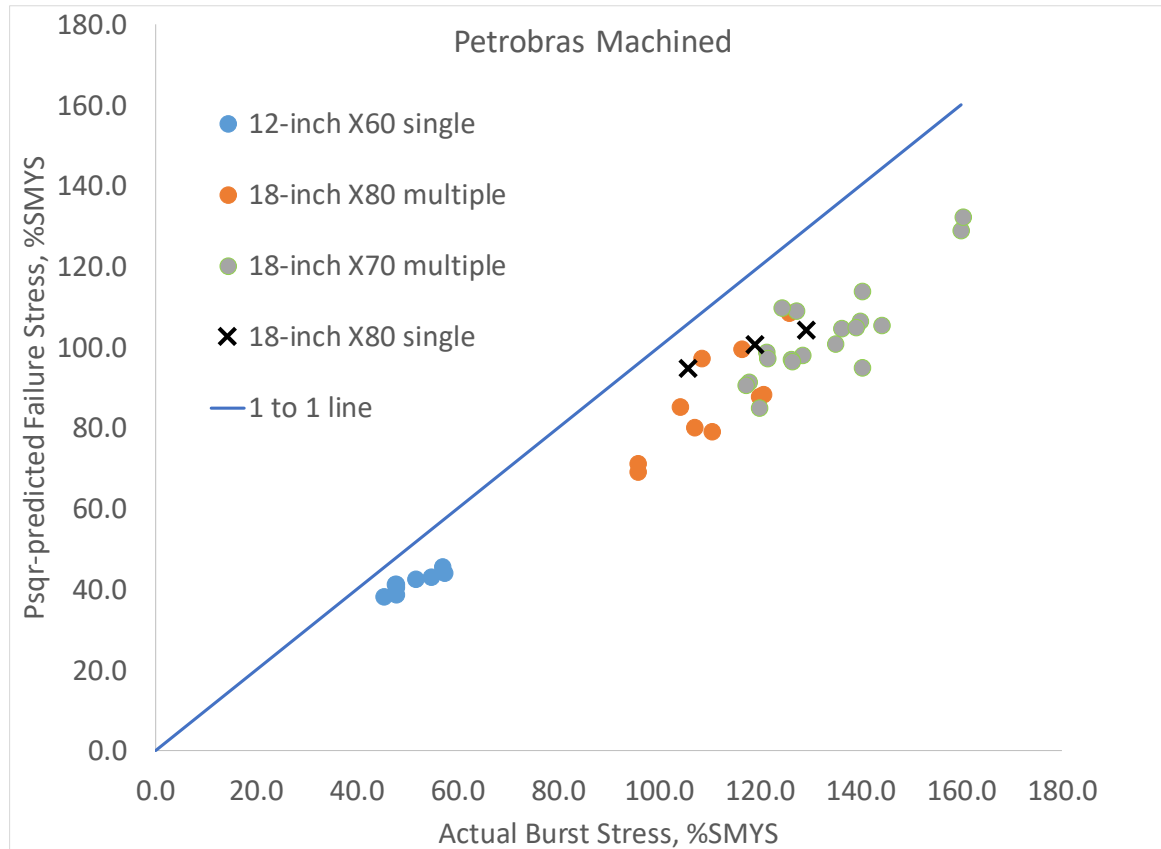
Why were More Validating Data Important?

- The main concern was that TC's burst tests all failed at hoop stress levels in excess of SMYS.
- The reviewers felt that confidence in the Psqr Model would be enhanced if it could be shown that the model would accurately predict failure stress levels when those levels were significantly less than 100% of SMYS.
- In earlier PRCI work, RSTRENG had been used successfully to predict the failure pressures of several failures that occurred at stress levels between 60 and 80 % of SMYS.
- Unfortunately, the records of the metal loss geometry of those cases proved to be inadequate for the application of the Psqr Model.
- Instead the Psqr Model was evaluated against 160 burst tests of pipe samples containing single and multiple machined corrosion-simulating notches.

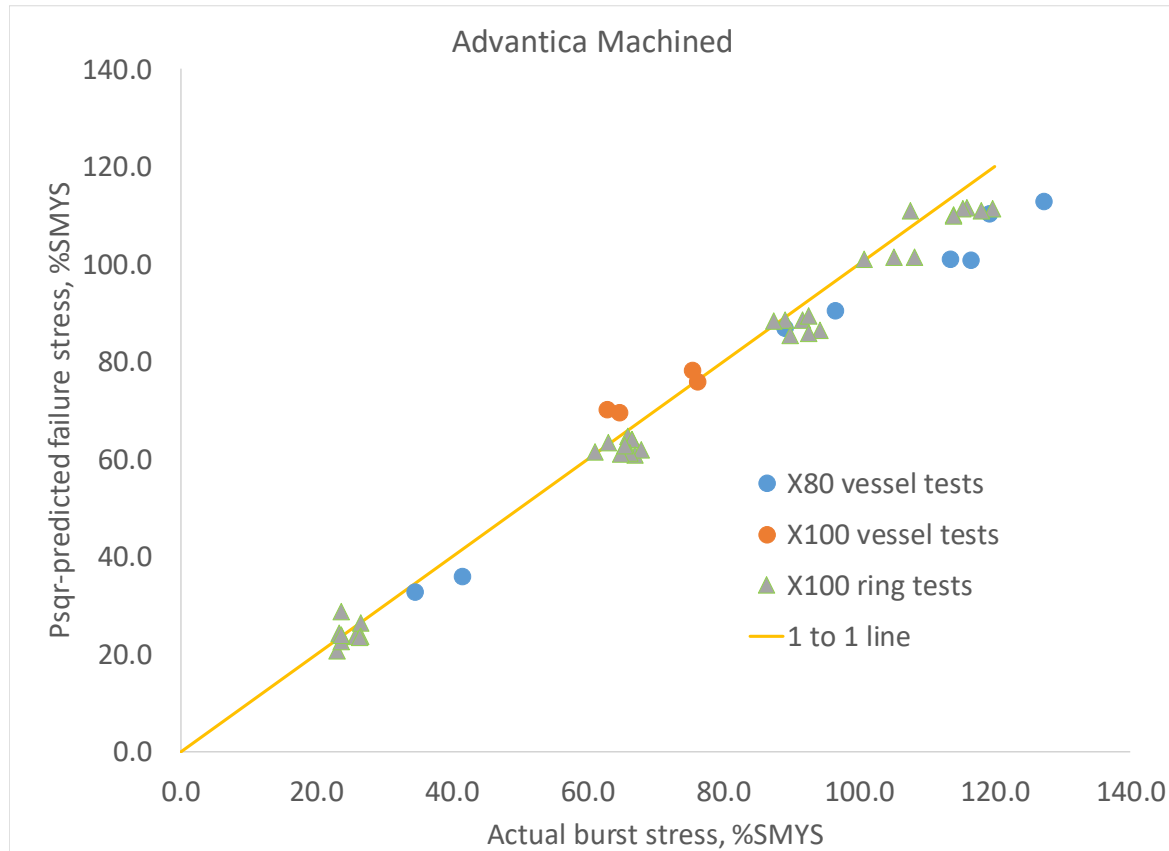
Validation of Psqr against Public Domain PRCI Data



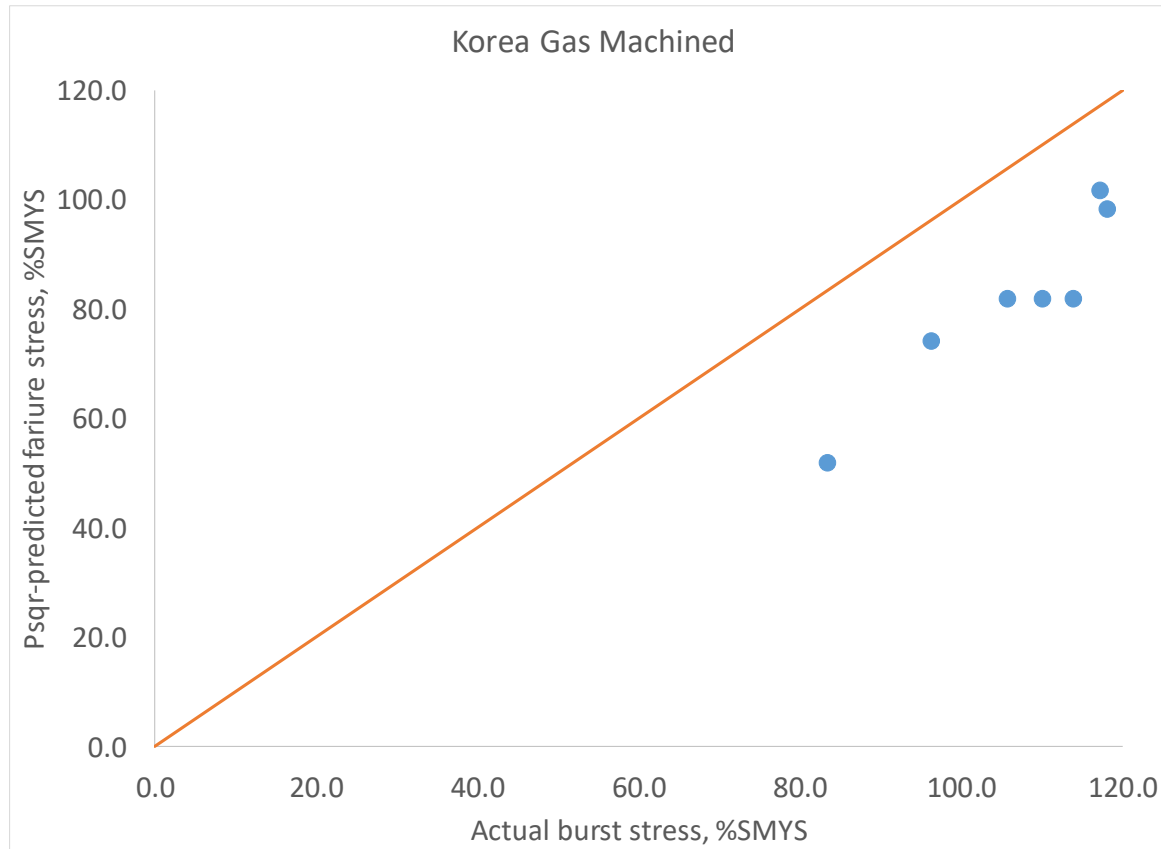
Validation of Psqr against Public Domain Petrobras Data



Validation of Psqr against Public Domain Advantica Data



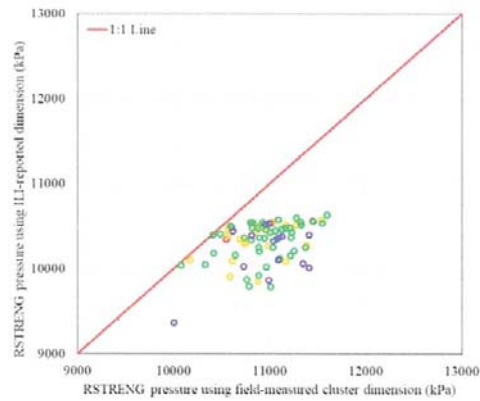
Validation of Psqr against Public Domain Korea Gas Data



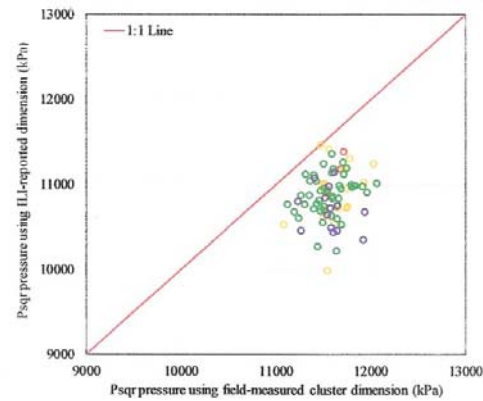
Using Psqr with ILI Data

- **Several of the reviewers raised questions about the use of the Psqr Model to evaluate ILI data:**
 - **Can ILI tools provide sufficient data for reliable Psqr calculations?**
 - **Because there will be fewer excavations using Psqr, is it more likely that a critical anomaly will be missed?**
- **In response, the TC team explained that the boxing and clustering of MFL anomalies provides sufficient information with which to create the 5 x 5 mm grid the works well for the Psqr Model.**
- **Ultrasonic thickness ILI tools already provide data on a grid with which the Psqr Model can be used.**
- **Most importantly, the TC team was able to show that the accuracy and precision of the Psqr Model enhances safety in comparison to simpler models. Unnecessary excavations do not enhance safety.**

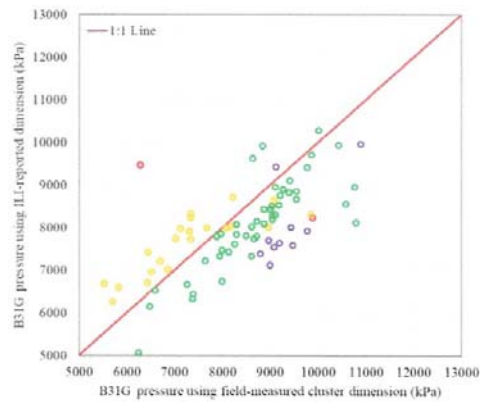
Using Psqr with ILI Data (continued)



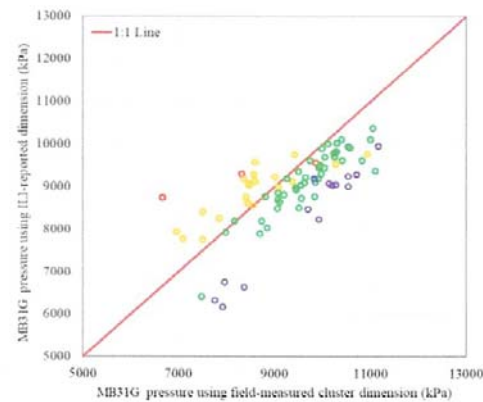
(a) RSTRENG



(b) Psqr



(c) B31G



(d) Mod. B31G

Conclusions/Recommendations

- **The consensus of the reviewers is that safe implementation of the Psqr Model requires a minimum level of due diligence regarding applying the model to ILI data.**
- **The safe use of the Psqr Model depends on conducting a corrosion management plan comparable to that employed by TC. The elements of such a plan are described in the TC's final report on the Psqr Model.**
- **It should be noted that the risk of missing a critical anomaly when prioritizing ILI data exists in conjunction with using any of the existing models (e.g., B31G, Modified B31G, RSTRENG) as well as with using the Psqr Model.**
- **The Psqr Model is more accurate and exhibits less scatter than the existing models. The model avoids over conservatism without compromising safety.**

Conclusions/Recommendations

The reviewers recommend that the Psqr Model be implemented for pipelines such that the failure stress does not go below either 100% or 90% SMYS as suggested in table below.

Maximum Operating Stress Level, %SMYS	Safe Failure Pressure Ratio	Minimum Acceptable Failure Stress Based On Psqr Model, %SMYS
80	1.25	100
72	1.25	90
60	1.5	90
50	1.8	90
40	2.25	90

Value to Members/Knowledge Transfer

- **Target audience: Pipeline integrity management specialists.**
- **Value: The use of the model safely reduces unnecessary integrity actions.**
- **Knowledge transfer recommendations:**
 - **TC's final report will be given to PRCI members and will be available for sale to the public.**
 - **A Microsoft Excel, VBA-based computer program and user's guide for the execution of Psqr calculations will be deployed to the PRCI members as part of the deliverables of Project EC-2-9.**
- **Questions/comments?**