9 Research Gap Analysis

9.1 Scope Statement

"Determine SCC related R&D issues that warrant further research."

The purposes of this section are to 1) identify gaps in the current understanding of SCC of pipelines and ways to manage the problem, 2) identify R&D that could be conducted to fill those gaps, and 3) prioritize the R&D topics based upon qualitative cost/benefit considerations. This section addresses the complete spectrum of R&D from basic research to understand the mechanisms of SCC in line pipe steels through applied research to understand the causes of SCC in pipelines to very applied R&D directed toward developing ways to manage the problem in the field. For each of those areas of research, this section summarizes the results of prior research, identifies remaining gaps, and discusses future R&D directions.

Four factors are considered in terms of the potential benefits of each R&D topic:

- **Safety** of the pipeline system clearly is the most important factor, so the relevance of the R&D to reducing the number of service failures is the first criterion.
- The potential impact on **cost reduction** is important to the pipeline industry and to the general public, because the costs of failures and the costs of prevention or mitigation eventually affect the cost of the product.
- The **size of the knowledge gap** also should be considered. If the level of understanding is relatively high, additional R&D may have a comparatively small effect on decisions regarding safety and cost.
- The **probability of success** in terms of a viable R&D approach that has a good potential for answering the remaining questions also should be considered.

It is not possible to quantify the above benefits, but considering them, with more emphasis on the first two, will allow various R&D topics to be ranked relative to each other in terms of potential benefits.

Quantification of the costs of required future R&D also is not possible without specific knowledge of the approaches that might be proposed by organizations that will conduct the R&D. However, based upon experience conducting R&D on SCC, judgments about the order of magnitude of probable R&D costs have been made.

9.2 SCC R&D Needs Discussion

Appendix A contains discussion of the history of R&D relating to both high pH and near-neutral pH SCC in several areas:

- Mechanisms of SCC
- Causes of SCC

- Methods for Managing SCC
    - Site-Selection Models
    - Crack-Growth Models
    - ILI Technologies
    - In-the-Ditch Sizing
    - Effect of Temperature
    - Steel Susceptibility

Each discussion area presents a summary of the background of R&D in the area, along with a discussion of gaps in the effort in each area. Generally, the discussion is targeted at making distinctions based on the four factors presented in Section 9.1 for each R&D area.

9.3 Prioritization of R&D Gaps

9.3.1 Criteria for Prioritizing

The research approaches to address the various knowledge gaps identified in Appendix A can be grouped into the following eight topics:

1. Develop improved site-selection models. In addition to research directed specifically at model development, this topic also would include basic research into the role of hydrogen in near neutral-pH SCC and the field environments that cause near neutral-pH SCC, because both of those subjects are related to identifying probable locations of SCC. This topic also is directly related to SCC Direct Assessment.
2. Develop improved crack-growth models. This topic would include research into the effect of stress fluctuations on crack growth and should deal with both high-pH SCC and near neutral-pH SCC.
3. Develop or identify new approaches or technologies for ILI, particularly for gas pipelines. This would involve a search for technologies other than the traditional approaches that rely upon magnetic-flux leakage or ultrasonics.
4. Develop new tools based upon emerging technologies such as EMAT.
5. Develop improved methods for sizing cracks in the ditch.
6. Determine the effects, if any, of temperature on near neutral-pH SCC.
7. Correlate SCC susceptibility with the composition and microstructure of steels.
8. Develop a fundamental understanding of the relationship between SCC susceptibility and the composition, processing, microstructure, and mechanical properties of steels.

The following section discusses the benefits of conducting more research into each of those topics in terms of the potential impact on safety, the potential for reducing cost, the size of the knowledge gap, and the probability that the research will be successful.

9.3.2 Benefit Analysis

Site-Selection Models. The ability to predict where SCC is likely to occur would be valuable in terms of safety because it would allow pipeline operators to focus their attention on areas of highest risk and to prioritize their actions. The ability to predict where SCC is not possible would be very important in terms of cost reduction because it could eliminate wasted costs of dealing with portions of the pipeline that are not susceptible to SCC.

Because of the many factors that affect the probability of SCC and the difficulty of measuring some of them, SCC detection and mitigation is challenging for operators. For example, soil chemistries and geological conditions are extremely complex, the condition of the coating may be unknown, the susceptibility of the steel probably will be unknown, and the history and relevance of prior operating conditions such as pressure fluctuations and cathodic protection levels may be difficult to interpret. Thus, the probability of developing a comprehensive, highly accurate predictive model may not be high, but even limited success could be very useful, especially with respect to direct assessment.

Crack-Growth Models. Once stress corrosion cracks are discovered in a pipeline, it would be very beneficial from a safety standpoint to be able to predict how long those cracks could be left in the line, either under normal operating conditions or modified operating conditions. The ability to relate crack growth to operating conditions also would be very important for direct assessment, as operating history would be one of the factors to consider in evaluating the probability of SCC in an area of interest. Improved crack-growth models also could have a large impact on cost reduction because they would be the basis for calculating optimum intervals between hydrostatic tests or ILI runs, and for areas where the maximum crack growth rate could be shown to be very low, the need for any remedial measures might be eliminated. Although simplified crack-growth models currently exist and are useful, significant technical challenges remain for making the models more accurate, especially involving issues such as the relationship of crack growth to pressure fluctuations, time-dependent changes in the creep resistance of the steel, and predicting the environmental conditions at the surface of the pipe. Nevertheless, reasonable approaches to those issues have been suggested and further improvements in the models, therefore, can be expected.

New ILI Technologies. Probably the ideal way to manage SCC would be to use a low-cost ILI technology that could locate cracks, differentiate them from other anomalies, and provide an accurate description of their sizes.

Unfortunately, current commercial tools are very expensive to run, and the most reliable ones are only applicable to liquid-filled pipelines. Therefore, there is a strong desire from both safety and cost perspectives to find a new, lower cost alternative, especially for gas pipelines. There is a significant challenge to conceive an approach that has not already been pursued by the ILI industry. However, several new concepts currently are being investigated, and other ideas should be encouraged and explored.

Develop and Evaluate Tools for Emerging ILI Technologies. An ILI tool for a pipeline must be extremely sensitive in order to detect the very small defects of interest and, at the same time, be very rugged to survive the journey through the pipeline. Therefore, the development of a tool can require tens of millions of dollars. New tools based upon technologies such as EMAT and circumferential magnetic flux leakage (MFL) are appearing on the market, but their reliability and accuracy have not been confirmed. If successful, these technologies could have a major impact on safety, but will be very expensive for operators to purchase and maintain.

In-the-Ditch Measurements. From a safety standpoint, it should not be necessary to remove very small stress corrosion cracks from a pipeline, especially since many most likely are dormant, and it certainly would not be economical to do so. Although current technologies are not completely accurate and are somewhat cumbersome, improvements are forthcoming.

Temperature Effects. Temperature effects on high-pH SCC are well enough understood that further R&D probably would not improve safety or reduce costs. While temperature effects on near neutral-pH SCC are less well established, field experience by the industry would suggest that temperature probably is not a significant factor for that form of SCC.

Correlate Steel Susceptibility with Composition and Microstructure. Although it would be highly desirable to build future pipelines from steels resistant to SCC regardless of the environment or stress, the challenges to designing such steels are significant, and other approaches such as improved coatings and surface treatments (shot peening or grit blasting) are relatively low-cost alternatives.

Develop Fundamental Understanding of Relationship Between Steel Susceptibility and Composition, Processing, Microstructure, and Mechanical Properties. A fundamental understanding of the factors that affect steel susceptibility would provide a much better basis for designing a resistant steel than would an empirical correlation, but it also would be much more expensive to develop.

The potential benefits related to each of the suggested research areas are summarized in Table 9.1.

9.3.3 Cost Analysis

The probable costs to complete each of the research areas mentioned above have been estimated based upon experience with similar previous research efforts. Because precise cost estimates would depend upon the specific approaches chosen for each area and the organization that would conduct the research, only order-of-magnitude estimates are possible at this time. The estimated costs are summarized in Table 9.2, where the following definitions apply:

Very High: Greater than 10 million dollars

High: Several hundred thousand to 2 million dollars

Medium: 1 hundred thousand to several hundred thousand dollars

Low: 50 to 100 thousand dollars

Table 9.1 Qualitative Rating of Potential Benefits from Various Research Areas

Research Area	Magnitude of Benefit			
	Safety	Cost Reduction	Size of Gap	Probability of Success
Site-Selection Models	High	Very High	High	Medium
Crack-Growth Models	Very High	Very High	High	High
ILI – New Technology	Very High	Very High	Very High	Medium
ILI – Develop Tool	Very High	Medium	Medium	High
In-the-Ditch Measurement	High	Medium	Medium	High
Temperature Effects	Low	Low	Low	High
Steel – Empirical Approach	Medium	Low	Very High	Medium
Steel – Fundamental Approach	Medium	Low	Very High	High

Table 9.2 Qualitative Rating of Costs to Complete Various Research Areas

Research Area	Cost
Site-Selection Models	High
Crack-Growth Models	High
ILI – New Technology	Medium
ILI – Develop Tool	Very High
In-the-Ditch Measurement	Medium
Temperature Effects	Low
Steel – Empirical Approach	Medium
Steel – Fundamental Approach	High

9.3.4 Summary of R&D Priorities

Based upon the benefit and cost analysis described above, each of the suggested research areas has been represented in Figure 9-1 in terms of a qualitative cost/benefit ranking. By necessity, the axes do not contain numerical values, and the positioning of each point is highly judgmental. It would be appropriate to think of the axes as logarithmic scales.

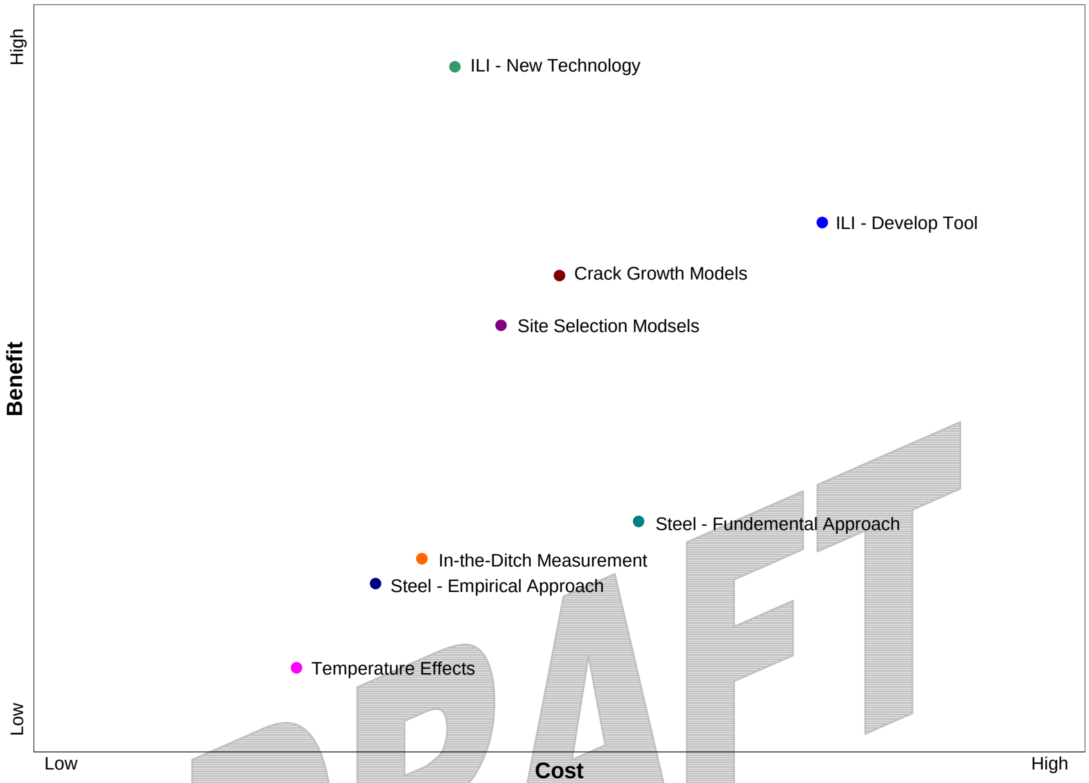

Figure 9-1 Qualitative Ranking of Research Areas by Cost/Benefit Ratio

9.4 References

(References to the R&D areas are contained at the end of Appendix A).