

# ANALYSIS OF RUPTURES AND TRENDS ON MAJOR CANADIAN PIPELINE SYSTEMS

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## **Abstract**

The number of ruptures per year is one of the National Energy Board's (the Board) measures of safety performance of the federally regulated oil and gas pipelines.

This measure was examined and analyzed over twenty, ten, and five years with respect to the rupture causes, ignitions, fatalities, injuries, pipeline age, in-line inspections, and the Board's safety interventions.

There were forty-six ruptures over the twenty-year period, twenty-three over the ten-year period, and seven over the five-year period (Ref. 1 and 2) on the 43,000 km of the regulated pipelines.

The average time from the pipeline installation to the time of rupture for the time-dependent rupture mechanisms is twenty-eight years.

There were three fatalities and fourteen injuries caused by the ruptures of the federally regulated pipelines over the past twenty years. Ruptures associated with fires of the gas and high vapour pressure pipelines caused most of the fatalities and injuries.

The dominant rupture causes are external corrosion, stress corrosion cracking, and third-party damage in this order of magnitude.

The pipelines that ruptured during the last five years were internally inspected. The in-line inspection tools could not properly detect the defects that caused the ruptures.

Regulatory interventions, such as public inquiries, Board Orders, and regulatory requirements, have reduced the number of ruptures due to the targeted cause.

The number of ruptures and safety consequences associated with them have decreased over the last ten years.

## **Keywords**

Oil and gas pipelines in Canada, pipeline ruptures, pipeline rupture causes, pipeline rupture ignitions, fatalities and injuries caused by pipeline ruptures, pipeline age at the time of rupture.

## Introduction

Pipeline safety is a matter of primary public interest. The Board is responsible for ensuring that companies comply with regulations concerning the safety of persons, as they may be affected by the design, construction, operation, maintenance and abandonment of pipelines.

One of the Board's goals is that the pipelines it regulates are safe.

The measures of the progress in the achievement of this goal are the number of pipeline ruptures per year.

Pipeline ruptures are analyzed by exploring the relationship between them and their causes, age, number of ignitions, fatalities, injuries, in-line inspections, and an attempt is made to correlate this information with the Board's interventions.

The analysis is attempting to find the trends of the pipeline ruptures and the influence of the regulatory interventions on the number of ruptures. Its findings could be used as a guide for the future regulatory efforts to improve pipeline safety.

The trend of rupture occurrences can only be established by analyzing the number of ruptures over several years. Periods of five years, ten years, and twenty years were selected for this analysis to elucidate short and long-term trends.

## Terminology

HVP liquids – hydrocarbons with a vapour pressure greater than 100 kPa absolute at 38°C.

Injury – a minor or major harm to the human body, but excluding fatality.

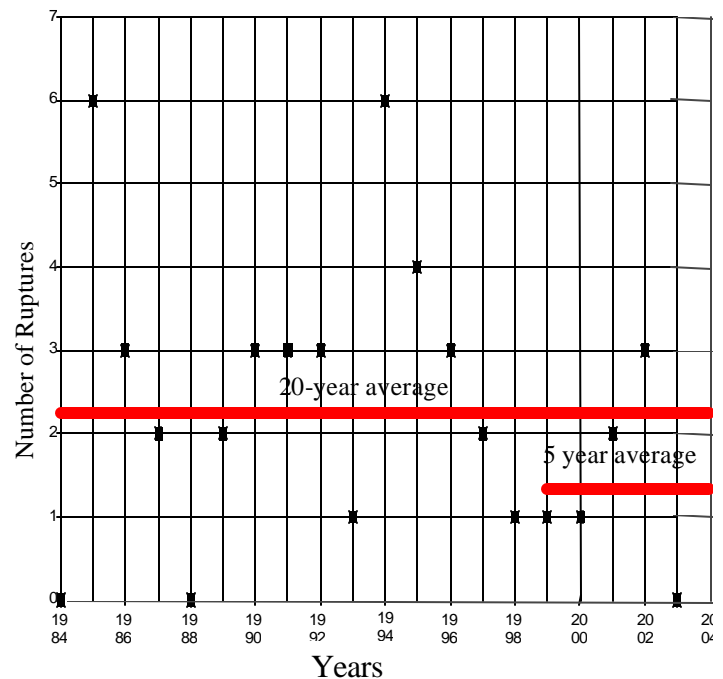
LVP liquids – hydrocarbons with a vapour pressure of 100 kPa or less at 38°C.

Rupture – a loss of containment event that immediately impairs the operation of the pipeline.

## Number of Ruptures

Forty-six ruptures occurred on pipelines regulated by the NEB over the twenty-year period from 01 January 1984 to 31 December 2003. The distribution of the number of ruptures per year is presented in Figure 1 and appears to be random.

Figure 1 – Number of Ruptures per Year



The National Energy Board has established a target of zero ruptures per year. This target has been reached in three years, namely in 1984, 1988, and 2003.

An average of 2.3 ruptures per year has occurred over twenty years and an average of 1.4 ruptures per year has occurred over the last five years (from 01 January 1999 to 31 December 2003). The difference between the long and short-term average of ruptures per year is shown in Figure 1.

Various hydrocarbons are transported in the regulated pipelines. The type of service fluid affects the safety consequences in the event of a rupture. Table 1 shows the number of ruptures sorted by the type of service fluid over the last twenty-year period.

Table 1 –Number of Ruptures By Service Fluid

Pipeline	Sweet Gas	Sour Gas	HVP Liquids	LVP Liquids	Total
Ruptures	21	6	5	14	46

As noted in Table 1, a significantly higher number of ruptures occurred on gas pipelines (twenty-seven) than on the liquids pipelines (nineteen) over the past twenty years.

The normalized number of ruptures per thousand kilometres per year is higher for liquids than for gas systems, as presented in Table 2.

In the last five years, a twenty-year trend was reversed; more ruptures occurred on the liquids pipelines (four) than on the gas pipelines (three).

Table 2 – Number of Ruptures by Service Fluid System

Service Fluid System	Number of Ruptures	Length of System (km)	Number of Ruptures / 1000 km / year
Gas	27	27800	0.049
Liquids	19	15200	0.063

It was observed that thirty-eight ruptures out of the forty-six ruptures occurred on the large diameter pipeline systems regulated by the NEB.

**Causes of Ruptures**

Causes leading to ruptures may be grouped into two categories according to the time required for development of a rupture condition:

**Immediate** Ruptures which occur at the same time as the causal event (e.g.: third-party damage or natural events where the pipeline fails immediately).

**Time Dependant** Ruptures which occur due to the continual degradation of pipeline material over time (e.g.: corrosion or stress corrosion cracking).

Seventy percent (thirty-two) of the ruptures resulted from time dependent causes during the last twenty years. The time dependent defect growth may be detected by in-line inspection. However, other methods are used for preventing the immediate ruptures.

Table 3 provides a summary of the causes of the ruptures over the past twenty years.

Table 3 – Number of Ruptures By Cause

Cause	Number of Ruptures
External Corrosion	13 *
Stress Corrosion Cracking	10 *
Third Party Damage	8 **
Natural Forces	4
Operational	3
Material Defect	2 *
Fatigue	2 *
Other	4

\* time-dependent  
 \*\* time-dependent or immediate

From Table 3, we can see that there are three dominant causes of ruptures (thirty-one ruptures): external corrosion, SCC, and third party damage. Under “other” causes included in Table 3 are hydrogen, sulphide, and weld cracking.

It is observed that the distribution of causes of ruptures in the first decade is significantly different from that in the second decade of the study period, as shown in Table 4 for the dominant causes.

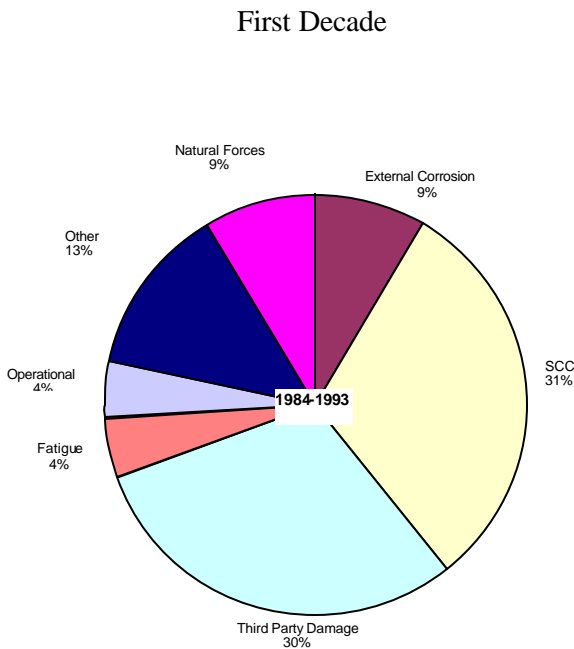
Table 4 – Number of Ruptures by Decade

Cause	01 January 1984 to 31 December 1993	01 January 1994 to 31 December 2003
External Corrosion	2 *	11 *
Stress Corrosion Cracking	7 *	3 *
Third Party Damage	7	1 *

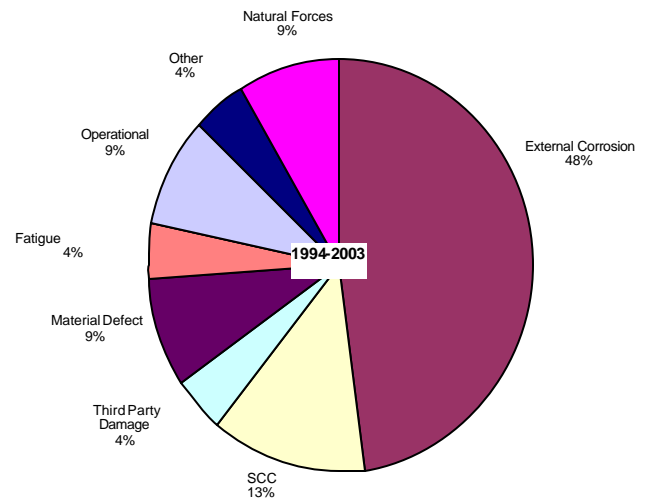
\* time-dependent

All of the pipelines that ruptures during the second decade (1994 – 2003) were in use during the first decade (1984 – 1993).

Figure 2 – Rupture Causes by Decade



Second Decade



In the second decade, the number of ruptures caused by external corrosion has significantly increased and those attributed to stress corrosion cracking and third party damage have decreased.

In the last ten years, out of a total of twenty-three ruptures, 11 were caused by external corrosion.

Seven ruptures occurred during the last five years; three were attributed to external corrosion, two to material defects (lamination and hard spots), one to SCC, and one to third-party damage. All seven ruptures, including the rupture attributed to third-party damage, were time-dependent.

In the last two years, no corrosion related ruptures were reported. This could be attributed to the introduction of integrity programs targeted to prevent ruptures caused by corrosion.

**Age of Pipelines at the Time of Rupture**

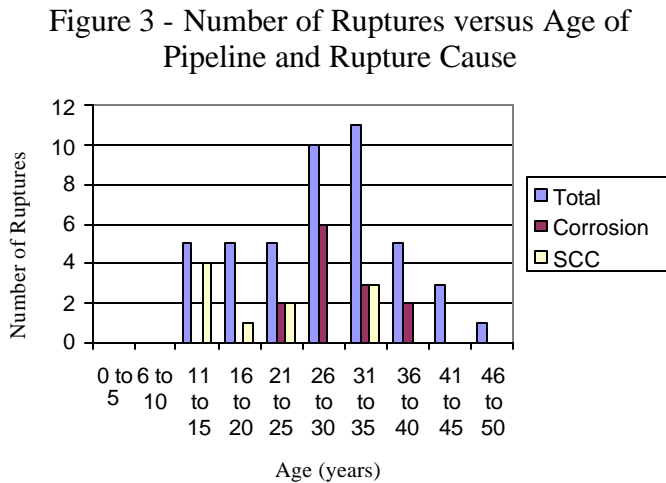
Figure 3 illustrates the relationship between the ruptures, pipeline age, and rupture cause.

Pipeline age means the number of years of operation from the year of installation to the year of the rupture.

Figure 3 also shows the number of ruptures due to the dominant time-dependent ruptures: SCC and external corrosion.

It is interesting to observe that no ruptures were recorded on pipelines which had been in operation for less than twelve years.

The absence of ruptures on new pipelines may be attributed to a number of factors, including the quality of materials, construction methods, and effective pressure testing.



The dominant time-dependent rupture mechanisms will be analyzed further in respect to the type of cause, time to rupture occurrence, and the type of coating.

Table 5 – Time to Rupture for SCC and Corrosion Defects

Cause	Average Time to Rupture (Years)	Shortest Time to Rupture (Years)	Number of Ruptures
SCC	21	13	10
External Corrosion	30	22	13

Table 5 shows that the average time to rupture for external corrosion defects is substantially longer than that for SCC. The same applies for the shortest time to rupture.

One of the many factors that contribute to the growth of SCC or corrosion defects is the type of

coating. All twenty-three ruptures that were attributed to SCC and corrosion occurred on pipelines coated with tape or asphalt. As shown in Table 6, the majority of ruptures (sixteen) that were attributed to SCC and corrosion occurred on pipelines coated with tape.

Table 6 – Number of Ruptures related to the Type of Coating for Dominant Causes

Cause	Tape		Asphalt	
	Number	Average Time to Rupture (years)	Number	Average Time to Rupture (years)
SCC	7	19	3	27
External Corrosion	9	29	4	31
SCC and External Corrosion	16	25	7	29

Data in Table 6 indicates that SCC grows faster in the tape coated pipe than in the asphalt coated pipe.

The average time to rupture, due to external corrosion, is independent whether the coating is tape or asphalt.

The data contained in Table 5 and Table 6, are for ruptures that occurred over the last twenty years.

The average pipeline age for all time-dependent ruptures over the twenty-year period is twenty-eight years, while the average pipeline age for seven time-dependent ruptures over the last five years is thirty-eight years.

### **Fatalities and Injuries**

The impact of ruptures on people are a direct measure of safety. The safety implications of ruptures can be measured as the number of fatalities and the number of injuries over the study period. Table 7 provides a summary of the number of fatalities and injuries within the last twenty years that were directly attributed to pipeline ruptures.

Table 7 – Number of Fatalities and Injuries Attributable to Ruptures

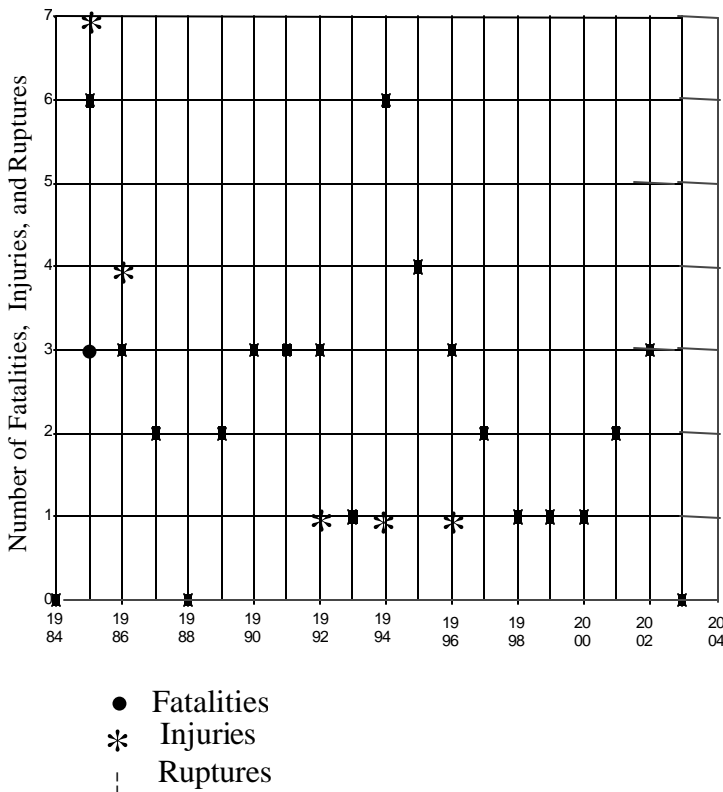
	Employee Injuries	Public Injuries	Employee Fatalities	Public Fatalities	All Injuries and Fatalities
Total	10	4	2	1	17

Over the last twenty years, there were three fatalities and fourteen injuries attributed to seven ruptures. There is a one-in-four chance that a rupture will result in injury and a one-in-twenty-three chance that a rupture will result in a fatality. Most of the fatalities and injuries were caused by human error.

Table 7 indicates that twice as many company employees were subject to fatalities and injuries as the members of the public.

Pipeline ruptures have not resulted in a fatality for the last eighteen years or an injury for the last seven years, as shown in Figure 5.

Figure 5 – Number of Fatalities, Injuries, and Ruptures Per year



In Table 8, the number of fatalities and injuries during the last twenty years is related to the service fluid which was transported when the rupture occurred.

Table 8 – Number of Fatalities and Injuries by Service Fluid

Number	Sweet Gas	Sour Gas	HVP Liquids	LVP Liquids	All Pipelines
Injuries	6	0	8	0	14
Fatalities	1	0	2	0	3
Total	7	0	10	0	17

All of the seventeen fatalities and injuries were caused by the rupture of sweet gas or HVP liquids pipelines. Ruptures of HVP liquids pipelines resulted in ten fatalities and injuries. The ruptures of sour gas and LVP liquids pipelines caused no fatalities or injuries.

The six ruptures of sour gas pipelines have not resulted in any fatalities or injuries although sour gas is the most toxic commodity transported in NEB regulated pipelines. A possible explanation is that sour gas pipelines are typically gathering lines located in sparsely populated areas.

### Ignitions

Of seventeen fatalities and injuries observed during the last twenty years, fourteen (82 %) were caused by fires of the escaping hydrocarbons.

Table 9 provides a summary of the number of ignitions associated with ruptures by service fluid over the last twenty years.

Table 9 – Number of Ignitions By Service Fluid

	Sweet Gas	Sour Gas	HVP Liquids	LVP Liquids	All Pipelines
Number of Ruptures	21	6	5	14	46
Number of Ignitions	12	2	4	0	18
Percentage of Ignitions	57	30	80	0	39
Injuries and Fatalities	7	0	10	0	17

From these observations, it can be concluded that HVP liquids pipeline ruptures were most susceptible to ignitions (80 %) and resulted in the highest percentage of fatalities and injuries (59 %). Fires resulting from HVP liquids pipeline ruptures are the leading cause of fatalities and injuries.

Only the gas and the HVP pipeline ruptures ignited. There were no ignitions of oil pipeline ruptures during the last twenty years.

During the last five years, one gas pipeline rupture self-ignited but did not cause any fatalities or injuries. The other six ruptures did not ignite.

### **In-line Inspection**

The effect of integrity management program implementation, such as in-line inspection (ILI), was examined to determine if these actions had an impact on the number of ruptures over the last twenty years.

The pipelines that ruptured in the first decade from 01 January 1984 to 31 December 1993 were generally not internally inspected by electronic high-resolution tools.

Fourteen of the twenty-three ruptures during the 1994 – 2003 period occurred on pipelines that had been subjected to ILI using different types of electronic inspection tools. A review of these internal line inspections shows that in:

- five cases, no defects were found because the ILI tool used was not capable of detecting the defect that caused the rupture;
- seven cases, the defects were found by the ILI tool, but were deemed to be non-critical;
- six cases, corrosion was judged to be non-critical;
- one case, the defect was incorrectly identified; and
- one case, the defect was identified after the rupture had occurred.

These observations suggest that the selection and detection capabilities of ILI tools, data interpretation, and defect sizing still require some improvements.

The pipelines that ruptured during the last five years were subject to an ILI. However, the tools that were used were not capable of detecting or correctly identifying the defect that resulted in the pipeline ruptures.

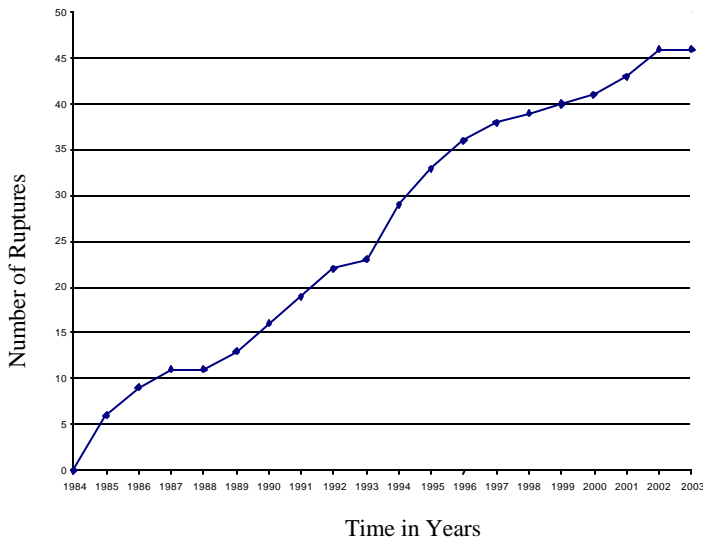
The present ILI tools are designed to detect one type of defect. Certain pipelines with different types of defects would have to be inspected with several in-line tools. The industry is responding by developing multi-purpose ILI tools that would combine detection capability of different defects into one tool.

The normalized number of ruptures during 1994 – 2003 was smaller than during 1984 – 1993. It is questionable that this reduction could be solely attributed to the use of ILI, because the number of ruptures caused by corrosion increased substantially during 1994 – 2003. With further improvement in defect detection and data processing, reduction of the number of ruptures should be expected.

The *Onshore Pipeline Regulations, 1999* introduced a mandatory requirement for companies to develop and implement integrity management programs. The implementation of this requirement should reduce occurrences of pipeline ruptures.

The cumulative rupture graph shown in Figure 6 shows the rate of rupture occurrences.

Figure 6 – Cumulative Total Number of Ruptures from 1984 - 2003



### Regulatory Interventions

Regulatory interventions are actions taken by the Board to address specific issues. In the case of ruptures, a number of regulatory interventions have been initiated by the Board to address specific causes as their consequences became evident. The data within this report indicates that in many cases, those interventions have been successful in reducing the number of ruptures attributable to targeted causes. Some examples are listed below:

#### Order Regarding Hard Spots

Hard spots are manufacturing defects where localized hardness is higher than the surrounding pipe material. Prior to 1983, several ruptures occurred due to cracking associated with hard spot defects. The Board issued an Order to replace the sections of pipelines that were known to contain hard spots. During the last twenty years, only one rupture was attributed to a hard spot.

### Inquiry Regarding Cracking in Sleeve Welds

In 1986, the Board held a public inquiry into an incident with two fatalities. The result of this inquiry was that the Board directed operators of liquid pipelines to identify and remove defective full encirclement sleeves on their systems and to develop technically sound welding procedures for welding on operating pipelines. Based on this direction, regulated companies examined and replaced defective sleeves and developed new welding procedures for welds that were subject to delayed cracking. Since 1986, no ruptures on full encirclement sleeve welds have occurred on NEB regulated pipelines.

### Public Awareness Program Regarding Third-Party Damage

No immediate ruptures as a result of third party damage have occurred since 1990. This may be attributable to the introduction of mandatory public awareness programs into the *National Energy Board Pipeline Crossing Regulations, Part II*, which were promulgated in 1988.

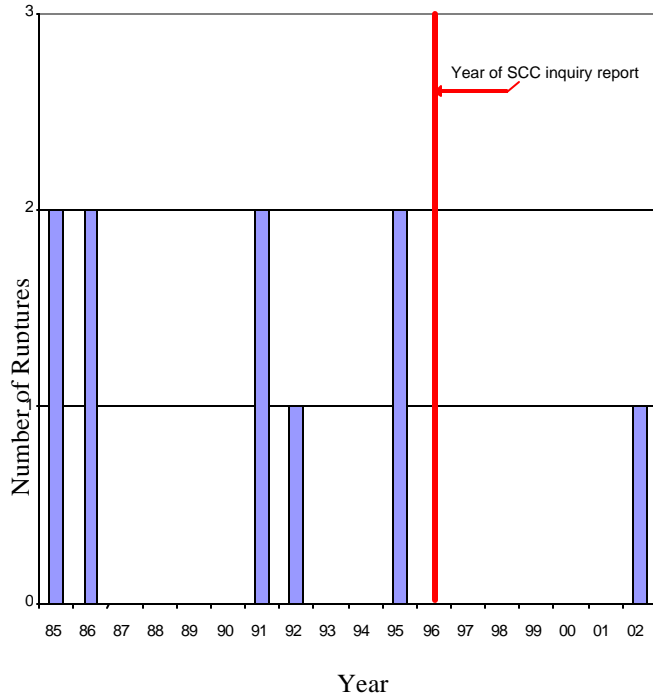
### Stress Corrosion Cracking Inquiry

In 1995, the Board observed that the number of ruptures attributable to SCC was increasing and, as a result, conducted a public inquiry. In the 1996 SCC inquiry report, the Board issued a number of recommendations including one which required companies to identify SCC and undertake mitigative actions to control or remove any significant SCC findings.

During the seven years following the inquiry report, only one rupture occurred as a result of SCC. This is an average of 0.14 ruptures per year. The average number of SCC ruptures in the eleven years prior to the inquiry was 0.90 ruptures per year. The effect of SCC inquiry on the number of ruptures is shown in Figure 7.



Figure 7 - SCC Ruptures During Last Twenty Years



- The dominant rupture cause in the last ten and five years is corrosion (Table 4).
- Regulatory interventions, such as inquiries, new requirements within regulations, and Orders, can reduce the number of targeted rupture causes (Figure 7).
- The safety performance of the National Energy Board regulated pipelines is improving (Figure 5).

**Recommendations**

To improve the pipeline integrity and safety, improvement should be made in:

- pipeline integrity management programs.
- the selection of pipeline coatings for new and rehabilitated pipelines.
- the detectability and accuracy of the ILI tools for existing pipelines.

**Conclusions**

The analysis found that regulatory interventions reduced the number of pipeline ruptures. The trends of ruptures observed over the last twenty years provide a useful guide for the future efforts of the Board and industry to further reduce the number of ruptures.

**Acknowledgement**

The help received from the colleagues at the National Energy Board to complete this paper is thankfully acknowledged.

**References**

1. National Energy Board. Focus on Safety. A comparative Analysis of Pipeline Safety Performance. January 2004.
2. Transportation Safety Board of Canada. Pipeline Investigation Reports, H001 to H0017.

**Summary of Observations**

The following observations have been made in this study:

- The number of fatalities and injuries due to ruptures has been decreasing over the last twenty years (Figure 5).
- During the last seven years, there were no fatalities or injuries caused by pipeline ruptures (Figure 5).
- The predominant cause of fatalities and injuries are ruptures that resulted in fires (Table 9).
- The highest safety risks are ruptures of HVP liquids pipelines (Table 8).
- The lowest safety risks are ruptures of LVP liquids pipelines (Table 8).
- The main root causes of ruptures are the defects resulting from the time-dependent deterioration processes (Table 3).

## **Disclaimer**

The views, judgements, opinions and recommendations expressed in this paper do not necessarily reflect those of the National Energy Board, its Chairman or members, nor is the Board obligated to adopt any of them.