



# The use of pigs in the Samarco pipeline to allow transportation capacity rehabilitation and integrity programme implementation

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## Synopsis

The Samarco pipeline, the longest in the world for iron ore slurry transportation, started operation in 1977 to transport concentrate from the Germano facilities, in the state of Minas Gerais, to the pelletizing plant, located 396 km away, in the state of Espírito Santo, on the south-east coast of Brazil.

Designed for a nominal capacity of 12 million tons per year, the pipeline reached 15.5 million/year due to operational improvement and, in late 2005, it was resized to transport 16.5 million tons per year, with the installation of a booster station.

In order to ensure the accurate performance of the system, a pipeline cleaning programme was carried out and, since it has been 29 years from the operation start-up, precise knowledge of the pipe condition would be fundamental to guarantee the success of the project.

The cleaning programme demonstrated the potential of operational gains from this initiative, and its effect on the corrosion control and future measures, which should be permanently adopted to maintain the improved capacity.

The intelligent pig runs provided essential data used to establish a pipeline integrity programme that allowed Samarco to develop a pipe repair plan based on the severity and significance of the features and to implement a future pipe replacement plan.

## Introduction

The Samarco pipeline went into operation in 1977, carrying the iron ore concentrate produced at the Germano facilities in Minas Gerais to the pelletizing plant in Ponta Ubu, Espírito Santo, over a distance of 396 km.

Designed for a nominal capacity of 12 mtpy, the system received a series of improvements until it was able to reach a throughput of 15.5 mtpy. At the end of 2005, a new booster pump station was added to the pipeline system, increasing its transportation capacity by one million tons per year.

The sizing of the new system considered that the pipeline would operate at full capacity after the booster station was in place, both in terms of pressure and flow.

In order for these requirements to be met, a project was developed to rehabilitate the transport capacity and ascertain the actual condition of the pipeline in terms of wear due

to abrasion and corrosion. This project involved the use of cleaning pigs as well as an intelligent pig.

## The booster station project

Under normal operating conditions, the discharge pressure at Pump Station 1 (PS1) reached values close to the maximum allowable pressure. On the other hand, Pump Station 2 (PS2) was not operating at maximum pressure, indicating the possibility to increase flow rate. However, as the two pump stations operate in series, any addition to PS2 would also result in additional flow at PS1. As the latter was already operating close to its maximum pressure, the only possible alternative for adding throughput to the system was to install a new pump station before PS2, at a lower level, reducing the discharge pressure on PS1.

In order to increase the flow rate at the pump stations, the pump gear boxes were replaced, providing a new reduction ratio. There was no need to replace the electric motors, since they had enough power to cope with this increase.

The booster station consists of two trains of two centrifugal pumps in series, one operating, and one standby.

Figure 1 shows the hydraulic gradient line of the new configuration.

## The transportation capacity rehabilitation programme

The transportation capacity rehabilitation programme was developed as a result of the need to increase the company's production rate and from the operating evidence of the decrease in the system flow rate.

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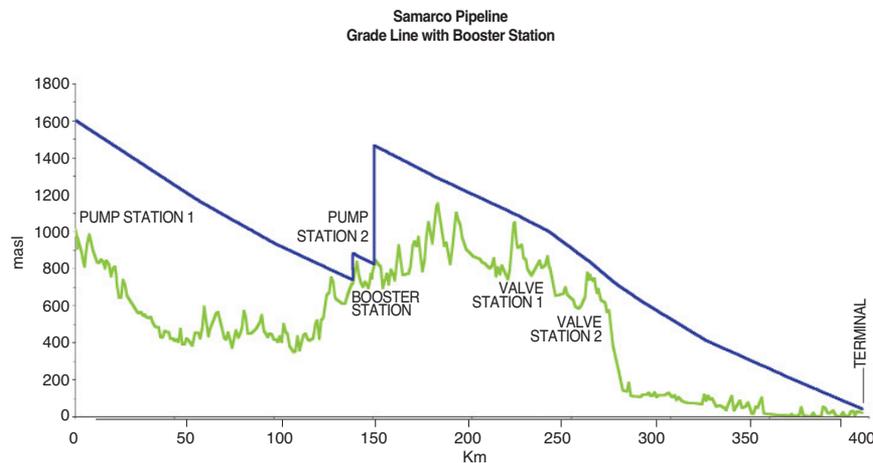


Figure 1—Hydraulic gradient after new booster station added upstream of PS2

### History of occurrences

During the development of the booster station project, an increase in the discharge pressure of Pump Station 2 was noted, and the following possible reasons were considered:

- Changes in the characteristics of the transported slurry
- Existence of particle deposition in the pipeline
- Occurrence of accelerated corrosion processes
- Presence of scale on the walls of the pipeline
- Combination of factors.

Figure 2 shows the increased discharge pressure in PS2.

### Changes in the characteristics of the transported slurry

An intensive programme of sampling, tests and studies of historical data was carried out to evaluate whether changes occurring in the variables could be affecting the behaviour of the slurry during transport.

In spite of some modifications in the concentrate production process, which led to a slight coarsening of the particles, no significant occurrence was found that would explain the changes in the pumping behaviour.

### Existence of particle deposition in the pipeline

Even though no significant variations were found in the characteristics of the concentrate, the deposits of coarse particles were considered as a probable cause for the increase in pressure. These deposits occur mainly in the lower points of the pipeline. Any changes in the production process and mineralogical characteristics of the ore particles could change the behaviour of the fluid during pumping. Additional studies were done to evaluate this possibility.

### Occurrence of accelerated corrosion processes

In view of the fact that the head loss increase was found to be more significant in the sections close to PS2, one of the most probable causes considered was the presence of an accelerated corrosion process.

### Presence of scale on the walls of the pipeline

Due to the addition of lime in the slurry to control pH, it was thought there could be scaling on the pipe walls. What

seemed strange, however, was the fact that this appeared to occur downstream from PS2, i.e., 150 km after the lime addition point. An explanation for this could be the formation of calcium carbonate scale on the walls of the pipe resulting from the addition of sea water to the pumps and the aeration of the slurry in the station storage tank.

### Combination of factors

After evaluating all of the probable causes previously outlined, it was concluded that the most probable cause was a combination of corrosion with the presence of calcium carbonate scale and deposition of coarse particles.

### The use of cleaning pigs

Since the most probable cause had been defined, the next step was to evaluate the available alternatives for eliminating the problem, and the most suitable solution found was the use of cleaning pigs.

The development of this project involved several phases, as described below.

### Adaptation of the existing facilities

The Samarco pipeline was designed to allow the use of cleaning pigs. However, the facilities had been sized for the use of foam pigs, which were inappropriate to solve the current problem. All of the launchers and receivers at the stations had to be resized and modified to allow for the use of new tools.

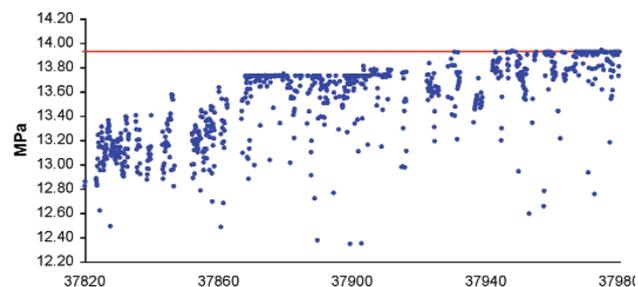


Figure 2—PS2 discharge pressure

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### Selection of service suppliers

One of the difficulties found during the design phase was selecting suppliers of cleaning pig services, as none of the firms consulted had any experience with iron ore slurry pipelines. After a suitable supplier was identified, the phases of the cleaning process were established:

- Identification of the most adequate tools
- Development of the run plan
- Establishment of goals
- Establishment of samples, collecting plan to confirm the effectiveness of the cleaning process.

Figure 3 shows some of the types of pigs used in the runs from Pump Station 2 and the Terminal.

### Execution of the cleaning programme

The cleaning programme was carried out in two separate phases:

- The first phase was in 2004, with runs between PS1 and VS1
- The second phase was in 2005 and 2006, in preparation for the intelligent pig runs.

After a series of runs was performed, it was concluded that the most suitable sequence would be as follows:

- *Investigation*—single pig, with caliper plate, without bits
- *Smooth removal*—double pig, in the configuration disc/cup/disc/cup/bits, with the bits adjusted to 100% contact with the internal wall of the pipe and low attack pressure
- *Transport*—double pig configured with disc/cup/brush/disc/cup/magnet. Whenever possible, use the jet spray option to improve the performance of the assembly

- *Aggressive removal*—double pig, in the configuration disc/cup/ disc/ cup/ bits. The bits must be adjusted to 100% of contact with the internal wall of the pipe and progressive attack pressure
- *Transport*—same configuration as outlined above
- Repetition of the sequences until the head loss reached the established values. Perform at least two runs in the aggressive configuration, with maximum adjustment of attack pressure. These also have the function of rectify/burnishing the inside walls of the pipes
- After the first cleaning phase, the subsequent runs would preferably be carried out with pigs configured without hard coated bits, in order to preserve the anti-corrosion protective coating.

### The pig runs

During the runs, samples were collected to evaluate the material removed and transported. These samples revealed the following:

- Insignificant presence of calcium carbonate
- Significant quantity of biogenic magnetite, indicating an occurrence of microbiological corrosion
- Presence of coarse particles that had settled along the pipeline due to unplanned variations in the production process, low efficiency of the protection systems, and possible changes in the mineralogical characteristics of the processed ore
- Based on these findings, it was confirmed that bacteriological corrosion arising from the addition of sea water to the main pumps and the presence of coarse particle deposits were the underlying causes of the problem.

Figure 4 shows examples of the material collected during the runs.



Figure 3—Types of cleaning pigs



Figure 4—Samples of material collected

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Figure 5—Samples of unusual objects

### Unusual findings

In addition to the expected materials mentioned above, various tramp items, such as screws, bolts, a bearing outer ring, a file, grinding media, very coarse particles, gate of valve, etc. were collected from the pipeline. These can only be explained by operating accidents occurring over the life of the system.

Figure 5 shows examples of these samples.

### Results obtained

The cleaning programme showed the possibility of:

- Removal of corrosion products adhered to the pipe
- Removal of existing scale
- Removal of coarse particles and materials settled on the bottom of the pipe
- Reduction in the head loss as a result of the internal cleaning of the pipes
- Increase in the flow rate of the system due to the reduction of the head loss.

Figure 6 shows the reduction in the head loss after the cleaning phases were completed.

### Precautions

After the conclusion of the cleaning phases, some precautions had to be taken to assure continuation of the benefits obtained.

### Corrosion control

Pipeline mechanical cleaning processes can reactivate and even accelerate corrosion processes that were previously 'stable', as a result of the removal of the formed corrosion layer, which acts as a protective coating. In order to keep internal corrosion under control, the following measures were adopted:

- After the removal of the layers that adhered to the pipe, the subsequent runs had to be executed with pigs configured so as not to remove any more of the corrosion film that had formed, providing a controlled protection of the pipe
- Investigation, characterization and quantification of the bacterial colonies present in the seal water samples. After a series of samplings and analyses, it was found that the main bacteria present were iron-reducing bacteria
- Identification of the most suitable reagents (biocides) to inhibit the action of the bacteria. Laboratory tests confirmed the possibility of using biocides

- Establishment of a programme to control the effectiveness of adding biocides, consisting of the periodic collection of samples at predefined points, upstream and downstream from the addition point, and counting of the bacteria, in order to confirm effectiveness and any requirement of adjustments in the dose of reagents
- Identification and installation of test specimens to control corrosion (biocoupons)
- Monitoring of potential environmental impacts caused by the addition of the biocide. Samples collected at several points indicated a degradation of the product during pumping, thus not presenting any risk of environmental impact at the end of the process.

### Control of coarse particle addition

Several samples collected showed the presence of much coarser particles than allowed for the pipeline, which pointed to the low efficiency of the protection screens installed in the concentrate production process (2 mm screens) and low retention capacity of the charge pump filters (6 mm screens). The following measures were adopted to minimize coarse materials in the pipeline:

- Implementation of a strict maintenance plan for the protection screens
- Resizing of the charge pump filter screens
- Installation of filters on the water process pumps at PS2.

Furthermore, a study programme currently underway seeks to relate the mineralogical characteristics of the currently produced concentrate to the occurrence of deposits during pumping.

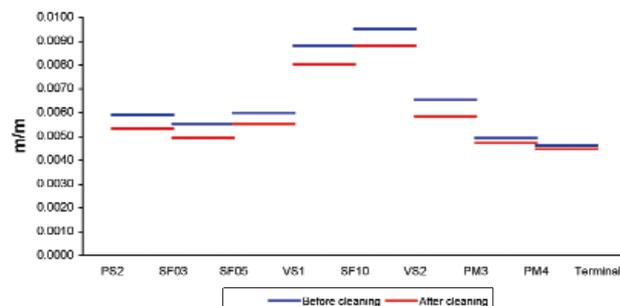


Figure 6—Head loss reduction

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### Conclusions

After several runs performed with a wide variety of cleaning pigs, the following can be concluded:

- It is perfectly feasible to adopt cleaning programmes to maintain the system's transport capacity
- The selection of the type of tool and its degree of aggressiveness depend on the internal condition of the pipeline
- Scraper pigs should be configured so as to rectify or burnish the roughness on the walls of the pipe. This is made possible with the adoption of bits coated with tungsten carbide or with similar material, distributed so as to have contact with 100% of the inner wall
- After reaching the desired cleaning level, maintenance should be carried out with less aggressive pigs, without using bits, keeping a protective anticorrosion coating inside the pipe
- Strict cleaning programmes demand strict subsequent corrosion control.

### The integrity programme

#### Background

The attainment of operational results was based on two main variables: compliance and integrity. The performance indicator 'Availability' was used for compliance control.

The pipeline integrity programme was based on readings of pipe wall thickness at 119 points distributed along its length. Due to unforeseen accidents that occurred between control points that showed normal wear measurements, this method proved to be ineffective. It was then decided to use intelligent pigs to determine the real condition of the pipeline, focusing mainly on localized defects and thickness reduction due to abrasion.

#### Compliance and reliability

Since the early operation of the pipeline until recently, availability was the only important indicator used for compliance with established goals. Since 2003, a reliability indicator was also adopted, namely MTBF (mean time between failure). This, in conjunction with availability, is a better representation of the system operational performance. Many factors affect these indicators and the most significant ones are the following:

- Intervention planning  
The corrective, preventive and predictive maintenance interventions should be planned so as to guarantee their adequate execution. The key point is to know exactly what, how and when to do
- Spare parts performance  
In order to achieve good performance, the development of adequate materials, components manufacture/recovery methods and suppliers is fundamental.
- Predictability  
The knowledge of the condition of equipment and facilities is also fundamental for compliance with the expected results.

The measured indicators show the success of the approach of the above factors .

Recently the performance indicators started to be influenced by the following problems that required special attention:

- Cracks on the main pump frames, caused by fatigue and end of useful life
- Performance reduction of some spare parts
- Pipeline leakage.

In order to solve the problem of frame cracks, a replacement plan was developed as an fundamental part of the pipeline integrity programme. The spare parts performance is being investigated with the sourcing of new suppliers and materials that will form an integral part of the system maintenance routine. The reoccurrence of leakages must be stopped with the adoption of a new pipeline integrity programme.

Figures 7 and 8 show the change of the Availability and MTBF factors.

#### Selecting the appropriate intelligent pig technology

The requirements taken into account in the selection of the appropriate technology were the following:

- Sufficient sensitivity to identify defects provoked by internal and external corrosion, localized or generalized, as well as wear due to abrasion
- Capability to determine the residual thickness of the pipe
- Possibility of using without significantly affecting the operating routine of the system.

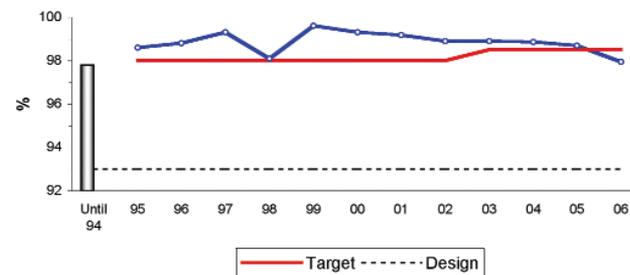


Figure 7—Availability

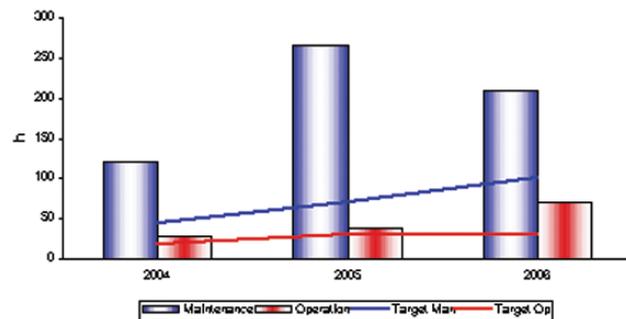


Figure 8—MTBF

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After evaluating the available technologies (magnetic flux leakage—MFL and ultra scan wall measurement—USWM) and considering the requirements above, the USWM option was selected.

### Difficulties encountered

The selection and application of the USWM tool presented some difficulties, which demanded special attention to the planning and execution of the programme:

- None of the suppliers had experience in performing services on iron ore concentrate slurry pipelines and their estimation of the required number of cleaning runs and the level of their effectiveness was an empirical task
- The transport velocity of the tool was an important parameter in the control of the runs. The lower the speed, the greater the precision in its readings. However, as the pig was transported in a batch of water, a significant reduction in the speed could result in the deposition of solid concentrate particles, in addition to affecting company production
- The control of the pumping pressure during the instrumented pig runs also required some changes in the operating routine in order to meet system requirements and allowable pig pressure requirements.

### Results

In order not to overly compromise the production schedule, activities between PS1 and PS2 had to be interrupted and were rescheduled for late 2006. The results of the runs made from PS2 to the terminal are outlined in Table I.

The reported defects were classified considering the ERF (estimated repair factor) and WTDP (wall thickness depth peak), based on ANSI/ASME B 31.G classification, as shown in Table II.

Table I

### Number of features

Section	Length (km)	Metal loss features	Internal	External	Lamination	Dent
PS2-VS1	88.1	1 949	1 799	150	390	133
VS1-VS2	31.6	972	884	88	167	50
VS2-Ubu	125.6	763	341	422	199	73

Table II

### Classification of defects

Criteria	PS2 – VS1	VS1 – VS2	VS2 - Ubu	
ERF	≥ 1.0	119	12	37
	≥ 0.9 and < 1.0	271	90	174
	≥ 0.8 and < 0.9	1 396	778	552
WTDP	≥ 30%	21	7	47
	≥ 20% and < 30%	144	465	136
	< 20%	1 784	500	578

### The pipeline integrity programme

Based on the data gathered, an integrity pipeline programme was developed that considered the main topics listed below.

#### Repairing defects

The reported defects were treated according to the flowchart in Figure 9 that prioritizes the sequence of repairs according to how critical they are.

#### Immediate repairs

The defects classified as  $ERF \geq 1$  and/or  $WTDP \geq 30\%$  were repaired immediately with the application of welded sleeves. Due to the high rate of defects found in the first few kilometres after PS2, the decision was made to replace 2.1 km of piping in that section.

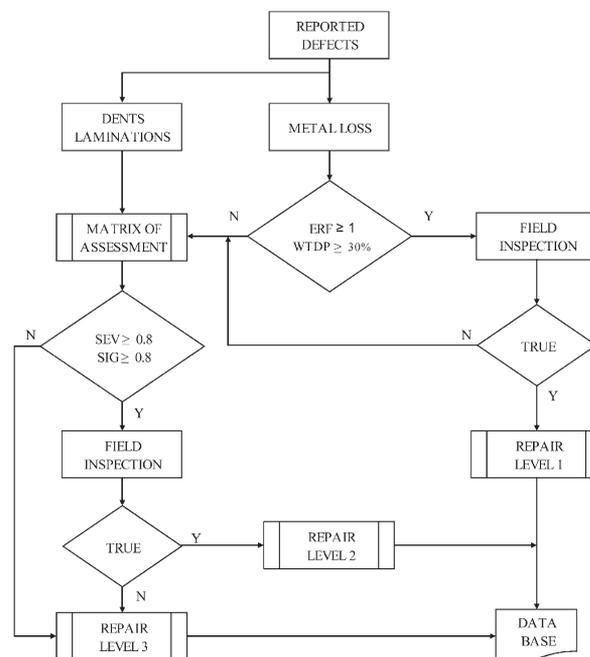


Figure 9—Flowchart: treatment of defects

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Table III shows the number of repairs made. Figure 10 provides examples of repairs.

### Scheduled repairs

Defects that were not treated according to the criteria adopted above were classified according to their criticality, resulting in a repair plan for short, medium and long term. Criticality is calculated using the formula:

$$\text{Criticality (C)} = \text{Severity (SEV)} \times \text{Significance (SIG)}$$

For the calculation of severity and significance, the following criteria were adopted:

- ▶ Severity—severity is a function of defect magnitude and readings precision, weighted according to their relevance, following the sequence:
  - Relevance of defects (RD) was determined using Table IV
  - The magnitude (Mag) of the metal loss defects (ERF and WTPD) was determined from Table V
  - The magnitude (Mag) of the lamination and dent defects was determined as shown in Table VI
  - The precision of the readings made by the US pig is a function of the percentage of the echo loss: the greater the loss, the lower the precision. The classification of precision is given by Table VII, which establishes the tolerance ranges for echo loss
  - The severity (SEV) of the defect was then calculated by the following formula:

$$\text{SEV} = (\text{Mag} \times \text{RD}) + (\text{Pre} \times \text{RD})$$

- ▶ Significance—significance is a function of the impact that a leakage caused by a defect could provoke. In this case, the socio-environmental impacts as well as the impacts on production are taken into account. In calculating significance, one considers the relevance and magnitude of the impacts, determined according to the following method:
  - Relevance of impacts (RI) was calculated using Table VIII.
  - The magnitude of the impacts (MagI) was calculated using Table IX.
  - The significance (SIG) of the impacts was then calculated by applying the following formula:

$$\text{SIG} = \text{MagI} \times \text{RI}$$

The points addressed by the above-mentioned method are then prioritized and distributed into short, medium and long range intervals for repairs.

Figure 11 shows an example of the distribution of the points in the section between PS2 and VS1. The results plotted in the graph represent overlapping points with the same classification

Table III  
Repairs

Features	Location	Quantity
ERF ≥ 1 and/or WTDP ≥ 30%	PS2 to VS1	18
	VS1 to VS2	15
	VS2 to terminal	45

Table IV

### Relevance of the defect and reading precision

Factor	Relevance ( % )
Magnitude ( Mag )	80
Precision of readings ( Pre )	20

Table V

### Magnitude—metal loss

METAL LOSS	
Defect classification	Mag
ERF ≥ 1 or WTDP ≥ 30%	10
0.95 ≤ ERF < 1 or 25% ≤ WTDP < 30%	8
0.80 ≤ ERF < 0.95 or 20% ≤ WTDP < 25%	6
0.60 ≤ ERF < 0.80 or 10% ≤ WTDP < 20%	3
ERF < 0.60 or WTDP < 10%	1

Table VI

### Magnitude—dent and lamination

DENT		LAMINATION	
Defect classification	Mag	Defect classification	Mag
Dent > 7% OD	10	Type A	2
Dent associated with seam weld	8	Type B	7,5
Dent associated with metal loss	6	Type C	9
Dent < 7% OD	2		



Figure 10—Examples of repairs

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Table VII

Precision	
PRECISION	
Echo loss ( EL )	Pre
EL ≥ 30%	10
20% ≤ EL < 30%	8
10% ≤ EL < 20%	6
5% ≤ EL < 10%	4
EL < 5%	2

Table VIII

Relevance of impacts	
Impact	Relevance ( % )
Socio-environmental impact	50
Loss of production	50

Table IX

Magnitude of impact	
Impact	MagI
Environmental preservation area	10
Crossing towns	6
Other areas	4
Loss of production in critical locations	8
Loss of production in less critical locations	6

### Planning of future pipe replacement

Based on the maximum allowable pressure calculated for the current pipe wall thickness measured by the US pig and on the wear rate projections, a plan was developed for future replacement of pipes between Pump Station 2 and the terminal.

The defects related to internal corrosion were treated in accordance with the latest revision of Code ASME B 31.G. Lamination and dents will be treated separately.

### Plan for new intelligent pig runs

The second phase of the programme provides for the performance of new instrumented (smart) pig runs starting in 2008 to evaluate the effectiveness of the measures adopted and collect new data. The frequency of the runs will be determined by these findings. The use of tools with the technologies such MFL, USWM, inertial and to detect cracks will be considered.

### Monitoring of the external coating and cathodic protection

As most of the defects found were external, due to flaws in the external coating of the pipeline and in the cathodic protection, a systematic monitoring programme will be put in place. The monitoring programme will involve mapping tests (pipeline current mapping—PCM and close interval potential survey—CIPS) every two years, starting in 2007, in addition to routine quarterly inspections. Another important point is that, also starting in 2007, the monitoring of the pipe-to-soil potential of the cathodic protection can be performed online, with the installation of optic fibre along the pipeline for data communication.

### Conclusions

In view of the length of operation of the Samarco pipeline and the occurrence of unforeseen events, the use of instrumented pigs for obtaining more information about the condition of the pipe seemed to be the most recommended alternative for the development of a system integrity programme. The results achieved so far have fully met expectations. The data collected have allowed the identification of weak points and the execution of the necessary immediate repairs, in addition to providing greater predictability for future actions. ♦

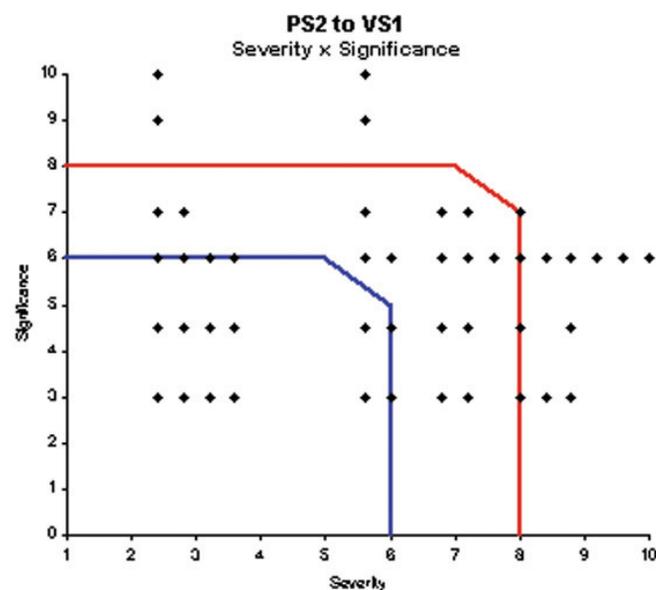


Figure 11—Severity and significance