National Transportation Safety Board

Washington, D.C. 20594

Report Date: 10 April 2012

CONTROL ROOM AND SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA) GROUP CHAIRMAN FACTUAL REPORT.

A. Accident

Accident Number:	DCA-10-MP-007
Type of System:	Liquid Transmission Pipeline
Accident Type:	Pipeline Rupture
Location:	Marshall, Michigan
Date:	July 25, 2010
Time:	about 5:57pm
Owner/Operator:	Enbridge Energy, Limited Partnership
Material Released:	Crude Oil
Pipeline Pressure:	520 Psig
Component Affected:	30-inch diameter pipeline.

B. Group Chair and NTSB Staff

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C. Introduction

Accident Summary

On the evening of Sunday, July 25 2010, at approximately 5:58 p.m.[1], a 40-foot long pipe segment in Line 6B, located approximately 0.6 of a miles downstream of the Marshall, Michigan pump station, ruptured. The Line 6B is owned and operated by the Enbridge Energy Inc. (Enbridge). The Enbridge control center in Edmonton, Alberta Canada was in the final stages of executing a scheduled shutdown of their 30-inch diameter crude oil pipeline (Line 6B) when the rupture occurred. The initial and subsequent alarms associated with the rupture were not recognized as a line-break through two start-up attempts and over multiple control center shifts. Residents near the rupture site began calling the Marshall City 911 dispatch center to report odors at 9:25 p.m. on Sunday; however, no calls were placed to the Enbridge control center until 11:17 a.m. the following day. Once the Enbridge control center was notified, nearly 17-hours after the initial rupture, remote controlled valves were closed, bracketing the ruptured segment within a three-mile section.

The accident resulted in an Enbridge reported release estimate of 20,082 barrels (843,444 gallons) of crude oil with no injuries or fatalities. The rupture location is in a high consequence area[2] within a mostly rural, wet, and low-lying region. The released oil pooled into a marshy area over the rupture site before flowing 700 feet south into Talmadge creek which ultimately carried it into the Kalamazoo River.

Line 6B was constructed in 1969 as a 293-mile long extension of the Lakehead pipeline system, stretching from Griffith, Indiana to Sarnia, Ontario. The failed segment was a cathodically protected, tape coated pipe manufactured by Italsider s.p.a.[3] per the 1968 API[4] Standard 5LX *Specification for High-Test Line Pipe* X52 specification with 0.25-inch thick wall and a double submerged arc welded (DSAW) longitudinal seam. The maximum operating pressure (MOP) for Line 6B was 624 psig; however, at the time of the accident, Marshall Station discharge pressure was limited to 523 psig due to a 2009 Enbridge imposed pressure restriction between Stockbridge and Sarnia. The maximum-recorded discharge pressure at Marshall, prior to the rupture, was 486 psig.

Lake-Head Pipeline and Line 6B System

Line 6B consists of seven active pumping stations[5] (figures 1a, 1b, & 1c) with tankage at various locations between Griffith, Indiana and Sarnia, Ontario, Enbridge uses a computation pipeline model (CPM) for detecting leaks on Line 6B. The type of CPM used is a Real Time Transient Model. At Enbridge, this model is referred to internally as the Material Balance System or MBS. The MBS utilizes three volume balance calculation time periods for detecting leaks. The two volume balance sections at the time of this

[1] All times are expressed in local accident time, Eastern Daylight Time.
[2] As defined by PHMSA under 49CFR§195.450.
[3] Societa Per Azioni (Italian). The Italsider pipe was purchased from Siderius Inc. of New York.
[4] American Petroleum Institute, New York, New York
[5] See Appendixes and Figures: 1a, 1b, & 1c

accident are Griffith to Marshall (GTMR), and Marshall to Sarnia (MRRW)[6].

Active Pump Station	Approx. Mile Post	Approx. Elevation (feet asl)
(Griffith Terminal) Active	465.6	628
(LaPorte Station) Active	499.4	792
(Niles Station) Active	538.2	796
(Mendon Station) Active	576.9	840
(Marshall Station) Active	607.6	920
(Stockbridge) Active	650.6	950
(Howell Station) Active	678.7	971.8

Figure: 1a Enbridge Energy Line 6B Active Pump Stations on July 25 & 26, 2010, Source: Enbridge Energy.

Figure: 1b Enbridge Energy Pipeline System Map from Edmonton, Canada to Montreal, Canada, Source: Enbridge Energy.

[6] See Attachment: 34 Line 6B Volume Balance Sections.

Figure: 1c   Enbridge Energy Line 6B System Map from Griffith to Sarnia, Source: Enbridge Energy.

C. Control Center

The Enbridge Energy, Inc, SCADA control center was located in downtown Edmonton, Alberta Canada. There were a total of twenty-five personnel comprising a shift. This included twenty-two line and terminal Operators, two Shift Leads, and one Material Balance System (MBS) Analyst (see figure 1). The supervisors and management are located in an area away from the control center. There was one Control Center Operation Supervisor responsible for the control center operation and shift lead group and another Control Center Operation Supervisor responsible for the oversight of the technical services group. The two shift leads are the acting supervisors of the control center overseeing the twenty-two consoles and also answering all emergency calls into the control center[7]. During interviews the shift leads indicated that there is an informal arrangement where one shift lead will oversee the pipeline operators while the other oversees the terminal operators. According to statements by the Control Center Operation Supervisor the role of the shift lead is to help the operators' trouble shoot issues that arise on the pipeline by prompting the operators to ask key questions and to follow procedures. The shift leads are not expected to be the technical experts in the room. The structure of the control center established by Enbridge puts the technical

[7] See Operator A1 interview transcript of July 28, 2010

expertise of pipeline operation at the operator level. According to interview statement from the control room supervisor, the control room operator has the ultimate authority to shutdown the pipeline if they believe conditions are unsafe.

The operator runs the pipelines assigned to their console. Each operator is responsible for multiple pipelines from their console. This can vary from 2 to 5 lines depending on the complexity of the operation. Line 6B was operated from a console along with lines 3, 6A, and 17. According to Enbridge control room supervisor, the control center operators are placed in groups consisting of back to back consoles or "pods" such as lines 4 and 6B. Line 4 was operated from the console directly behind Line 6B making the 4 and 6B consoles a group. According to the control room supervisor each group consists of two operators that are to act as a technical resource for one another when problems arise. Within the control center there are several large flat screen panels within view of all the controllers. The intent is that problems on any line may be displayed on the screens for the entire room to troubleshoot or discuss. The Line 6B console, according to statements in the interviews, was one of the more difficult consoles to operate.

The pipeline operators perform startup and shut downs on the pipeline and ensure that adequate flow rates are maintained and that scheduled deliveries are made to the terminal locations. The pipeline operators have to monitor multiple batches of crude in the line and work closely with terminal operators at other consoles to see that they are delivered correctly. Every two hours the controller performs an automatic balance calculation using the commodity tracking system to double check deliveries. To maintain the correct flow rate on the line, the operator must manage pressure set points at the pump stations, valve positions, starting and stopping pumps within a station, setting pump speeds or holding pressure at the delivery tanks. When the system is running, the operator observes changes in the pressure through the color and number indications that appears on the line display

The control center operator must also monitor the alarm screen and historical SCADA data (events log) which tracks commands, acknowledge high priority alarms of S4-S8 and monitor low priority notifications of S2-S3.

The operators most times when they receive status alarms of any form communicates to the Shift Lead, and sometimes with the MBS Analyst, they take the MBS Analyst interpretations of the MBS as being conclusive and may or may not conduct further investigations.
See attachments [2 – 3]

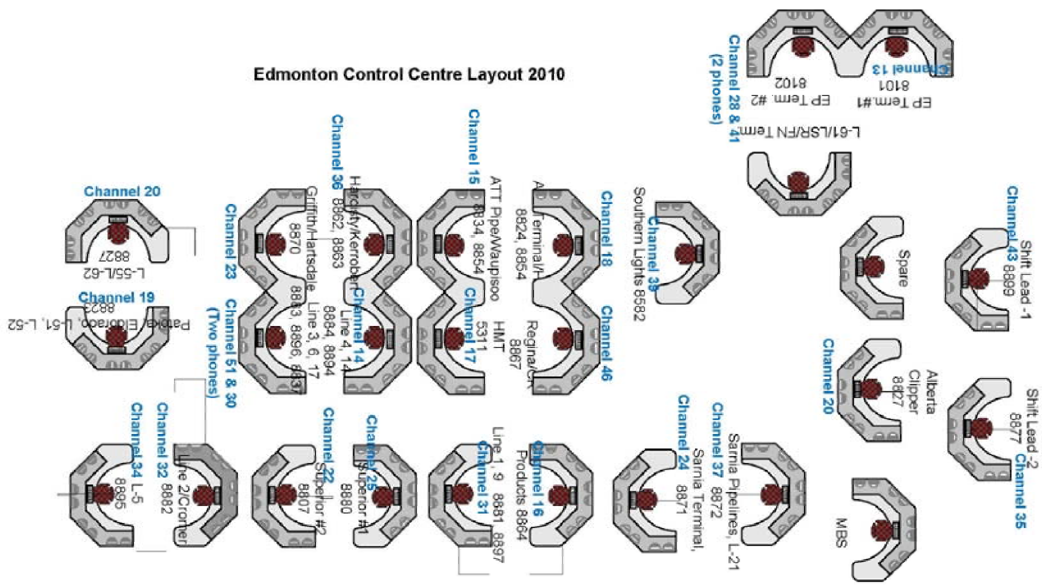

Figure: 1d [Attachment 1]

The role of the Material Balance Analyst is to serve as the systems expert over the leak detection software system. The MBS analyst is contacted by the shift lead or operator when a material balance alarm is received. According to interviews transcripts of Material Balance Analyst A their function is to tell the operator the result of their analysis, make sure the software is maintained and running the way it should. The MBS system involves examining several screens to make a determination as to whether the model is working properly or not. The MBS analyst and operator have access to similar MBS displays; however, according to statements by operators they are not trained to use the material balance system.

If the MBS analyst requires further technical support, there is an on-call twenty-four hours seven days a week MBS engineer that may be contacted[8].

A control center operator typically operates more than a single pipeline. Line 6B console included lines 3, 6A, and 17 as well as line 6B. Shifts could be morning to

[8] Interview of Control Center Engineer on July 30, 2010

evening with each shift covering a12 hour span beginning at 6:00 a.m. to 6: p.m. vice versa, local time.
See Attachment [22]

D. Incident Overview

Description of Line 6B Pre-Shut down, Shutdown and Start-up events

Shift A - July 25, 2010

On July 25, 2010 at about 8:00 a.m. shift A, started as a normal day shift with Operator A1 and Operator A2 overseeing Line 6B which was already running. Operator A1 was a control room operator with 29 years of experience in pipeline operation that had just started re-qualification to the control center full time after being away from the control center for 6 months on disability leave and was being mentored by another controller, Operator A2 with 30 years of experience as a pipeline operator.

A planned shutdown of Line 6B had been scheduled from 7:30 p.m. July 25, 2010 to 4:00 a.m. on July 26th. At the suggestion of Operator A1 who had concerns over the scheduled conflict shutdown, Shift Lead A2 contacted schedule department about the time as a result it led to a combination of two start-ups and shut downs as originally scheduled; the shutdown was moved one hour earlier from 6:30 p.m. July 25, 2010 to 4:00 a.m. July 2010[9].

At 11:24 a.m. an Electrician A spoke with Operator A1 to find out when the In-line Inspection tools (pigs)[10] in Line 6B would be at the Niles pump station so that he could bypass the station. Line 6B was scheduled to be shut down at 6:00 p.m. and re-started at 4:00 a.m. on July 26, 2010, the reason for the shutdown was due to unavailability of oil in tanks at Griffith to ship. Enbridge planned to have the entire quantity of oil at the location before they resume pumping when the customer would receive it. This was stated as scheduled delivery conflict[11].

At 5:37 p.m. Electrician A called Operator A1 and told him he was heading to Niles Station to be ready for the bypass, and by 6:08 p.m. Niles Station was bypassed for pigs' passage, the required valves were closed, and locked out.

According to Enbridge SCADA data log report and Operator A1 interview transcripts, at 5:55 p.m., as part of the planned shutdown, he talked to the terminal operator to stop the booster pump at Griffith, then issued a stop command to the first of two pumps at the most upstream station; Griffith. At 5:56 p.m. the second pump at Griffith was given a stop command. Within seconds of stopping the second pump at Griffith, Operator A1 issued a stop command to the pump at La Porte, the next downstream station.

[9] Enbridge Control Center Transcript at 4:34 p.m. on July 25, 2010
[10] Pig, this is an In-line Inspection tool for pipeline cleaning and inspection
[11] Enbridge Control Center Transcript at 4:34 & 4:36 p.m. on July 25, 2010

According to Enbridge SCADA data log report at 5:57 p.m. Operator A1 increased the holding pressure to 200 psig at Stockbridge, delivery location after pressure reduction on Line 6B due to set point changes. Within seconds of changing the holding pressure set point, Operator A1 issued a stop command to the only pump at the Niles Station. In preparation for stopping pumps at Mendon, Operator A1 reduced the suction pressure set point by 5 psig at the Mendon and Marshall Pump Stations.

At 5:58 p.m. Operator A1 issued a stop command to pump Unit-1 the Mendon Pump Station approximately 40 miles upstream of the Marshall station. Within seconds of stopping the pump at Mendon, at 5:58 p.m., Operator A1received a high priority alarm from the Marshall Station indicating invalid pressure from the Line Pressure Monitor(LPM)[12] system which according to Enbridge it implies the transmitter received a zero pressure. Operator A1 also issued a stop command to pump Unit-2 at Marshall. At the same time that the high priority alarm was received, there was a medium priority [13]alarm at the Marshall station, the final downstream station, indicating low suction pressure below 25 psig. In response to the low suction pressure, the Marshall station entered into a local shutdown initiated by the PLC[14] to protect the pumps. Operator A1 received a notification over SCADA indicating that the pump at Marshall has stopped. Within seconds after 5:58 p.m. the low suction pressure alarm cleared. These alarms were acknowledged by Operator A1 and disappeared from the unacknowledged alarm log display but remained in the historical SCADA data.
See Attachment [29][15]

Also according Enbridge SCADA data log report[16] at 5:59 p.m. Operator A1 increased the holding pressure at the Stockbridge to 250 psig. However, between 5:59 p.m. and 6:00 p.m. three additional S-6 high priority alarms were received from the Line Pressure Monitor indicating invalid pressures at Marshall. A FACMAN for 5- minutes MBS alarm was created at approximately 6:02 pm[17].

At 6:03 p.m. an S-6 high priority material balance system (MBS) 5-minutes alarm was received on Line 6B between Griffith and Marshall on shutdown, according to Enbridge this was a leak detection alarm indicating the imbalance has exceeded 5 minute threshold. This information was passed to the MBS Analyst A for analysis through Shift Lead A2. Prior to the above, at 6:02 p.m. Operator A1 called the pig tracker informed him he had shutdown at 5:59 p.m. but with a plan to re-start Line 6B at 4:00 a.m. on July 26, 2010.

At 6:06 p.m. the 5-minutes MBS alarm displayed cleared, this indicates the MBS imbalance no longer exceeded the alarm threshold. MBS Analyst A called back Operator

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[12] LPM is the Line Pressure Monitoring System that Enbridge uses for overpressure protection on their pipelines
[13] Medium priority alarms appear as S-4 in the alarm and event logs
[14] Programmable Logic Controller
[15] See Attachment : 29 – Marshall Station PLC Pump Shut down
[16] Supervisory Control and Data Acquisition (SCADA) Data Log
[17] See Attachment: 33 FACMAN generation for July 25 & 26, 2010

A1 and told him he had column separation and that was causing the alarm. Operator A1 said he is sure it is Marshall and it would probably be there until they start up back at 4:00 a.m. the next day[18]. MBS Analyst A said he agreed with that. The cause of the column separation was not investigated further. However, during this shift, Operator A2 the mentor to Operator A1 according to the interview transcripts stated she was located at a console besides the mentee and had to work on some special projects while Operator A1 was operating the line. But she mentioned prior to the shut down that Line 6B was scheduled to be shut in at Stockbridge, then started up and shut down again at Sarnia after about one hour to one-half hour of pipeline operation, to avoid shutting down and starting up twice which could affect the pipeline they suggested that they shut down the line after Stockbridge delivery.

Shift B July 26, 2010

During interviews with Operator A1 and Operator B1, Operator B1 stated that he was never told of the alarms and low pressures received during the shift A shut down. Shift B started at about 8:00 p.m. on July 25, 2010. At this time according to the alarm and event logs and transcripts Niles Station had remained on bypass[19] from 6:08 p.m. on July 25, 2010[20].

At 4:04 a.m. Operator B1 observed Valve 632.89 with unknown state due to loss communication as he proceeded to start Line 6B. He told Shift Lead B2 that the Valve should not have been operated, but he sent an open command to it in case it decides to close back. Shift Lead B1 acknowledged his actions as positive.
See attachments [2, 6, 31, and 39]

At 4:12 a.m. Operator B1 called MBS Analyst B told him that on Line 6B he was just starting up and had received 5-minutes MBS alarm. He was asked if he had column separation then he confirmed it was[21]. MBS Analyst B said he would get back to Operator B1. According to Enbridge in the SCADA Data Log it was 5-minutes, S-6 high priority volume balance alarm between Griffith and Marshall. This was an alarm generated from the material balance system[22] which indicated the 5-minutes imbalance had exceeded the alarm threshold.

At 4:16 a.m. Operator B1 received a 20 minute, S-6 high priority, volume balance alarm between Griffith and Marshall. This alarm was generated from the material balance system indicating the 20-minutes imbalance had exceeded the alarm threshold.

At 4:22 a.m. Operator B1 received a second 5 minute, S-6 high priority, volume balance alarm between Griffith and Marshall. This alarm was generated from the material

[18] While Line 6B was shutdown from 5:58 p.m. to 4:00 a.m. about 75 miles of pipeline was sectionalized between valves, and left to drain (leak) out of the ruptured location.
[19] By-pass- This is closing some sectionalizing valves at Niles Station to prevent the In-line inspection tool (pig) not entering the station but to continue on the mainline.
[20] Enbridge Control Center Transcripts
[21] Enbridge Control Center Transcripts
[22] Material Balance System – This is same thing as the Leak Detection System according Enbridge.

balance system or indicating the 5-minutes imbalance had exceeded the threshold and has been in that state for over 10 minutes.

At 4:23 a.m. Operator B1 called Shift Lead B2 again told him that Menden pump had reached 10 minutes since it was started up, and with concerns about pressure, thinking another pump would be needed at Menden, but when he noticed slight pressure increase at Marshall and thought there was increasing pressure, he concluded additional pump would not be needed.

At 4:24 a.m. Operator B1 called Operator B2 who informed him the line was pretty slow and that he maintained the terminal booster pump holding pressure at 150 psig. Operator B1 said unless Line 6B is leaking, that he thought they must have drained[23] it up completely because they were not getting any pressure down the line, however, he was going to start the bigger pump at Mendon since they have gotten the small unit out of suction at Menden and if Marshall doesn't start reacting then he will shut down.

Between 4:36 a.m. and 4:57 a.m. there were more material balance system alarms generated on the SCADA system. This includes;

- 5 minute, S-6 high priority, volume balance alarm indicating the 5-minutes imbalance had exceeded the threshold and has been in that state for over 10 minutes,
- 20 minute, S-6 high priority, volume balance alarm indicating the 20 minutes imbalance had exceeded the threshold and has been in that state for over 10 minutes.
- 2 hour, S-6 high priority, volume balance alarm indicating the 2 hour imbalance had exceeded the threshold and has been in that state for over 10 minutes[24].

At 5:00 a.m. Operator B1 called Shift Lead B2 let him know they were not gaining anymore pressure at Mendon, but though they were not losing, they were not gaining at Mendon anymore, instead it just leveled out. Shift Lead B2 asked him if he had sorted it out, but Operator B1 said no, then he told him to give it one more minute. Shift Lead B2 asked him if he was doing 1800 cubic meter per hour and he said no about 1500 cubic meter per hour which he calculated was about 20 minutes at 20.7 miles. Shift Lead B2 also called Operator B2 and asked him how much he had added up in per hour, if it was up to 260 and he responded 269. Line 6B was shut down[25] at approximately 5:00 a.m.

At 5:04 a.m. Operator B1 called Pig tracking Supervisor to let him know they have shut down Line 6B due to some technical difficulties.

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[23] Drained – Condition where a pipeline is emptied-out of oil during a prior shutdown.

[24] See Figures 11, 12, and 13

[25] Again about 75 miles of pipeline was isolated between sectionalizing valves, and allowed to leak out of the ruptured pipe.

At 6:10 a.m. Electrician A called Operator B1 to let him know he was about Niles Station and inquired when he would be needed at the station. Operator B1 told him Line 6B was shut down, because they were trying to start up but did not get any pressure into Marshall and had to be shut down until they could investigate the leak, if a leak. Electrician A then asked him if they had phoned anybody at Marshall, but Operator B1 said no they were working on it until they could see what was happening first from the control center. The interview transcripts of this Electrician indicated he communicated with the Marshall PLM[26] shop about the Line 6B conditions.

During shift B start up of Line 6B at 4:00 a.m. a draft "suspected column separation procedure", provided by Operator B3, was used to operate Line 6B longer than a company stated procedural 10 minutes. Operator B3 had received and previously used the draft procedure provided by Shift Lead A2 in May 2010.
See attachment [7, 8, & 9]

At 6:34 a.m. Shift Lead B1 called the on-call Control Center Operation Supervisor told him they had some technical difficulties on Line 6B. Shift Lead B1 mentioned that they started up Line 6B and it was drained off and quite often they have column separation at Marshall and typically have to fill it. That they started Line 6B and did not get pressure at Marshall Area for some time but got up to 4 pounds and the pressure did not increase. So they pumped in more into the pipeline expecting pressure but got nothing. They calculated their numbers looking at draining 632 cubic meters roughly. And once they figured they were not getting pressure, and since they got the numbers calculated[27] they decided that 600 cubic meter should fill it. He said they had shutdown, had put in 600 cubic meters but they took out 270 cubic meters at Marysville which does not seem right. The operators and the MBS Analyst B calculated the pressure, they could not have put in 1,600 cubic meters to pack the line and nothing came out. As they discussed Shift Lead B1 questioned MBS Analyst B why the column separation would not have filled if they put in 1600 cubic meter on the startup. But MBS Analyst B stated that it went into the line pack because they were pushing it through 137 miles of pipeline to get any flow and it was a fairly low pressure on start up. The Control Center Operation Supervisor replied by asking "Yeah but typically it's not that much volume, right?"

According to Shift Lead B1, MBS Analyst B said they were not pumping hard enough into the column separation[28] and with more pressure they should be able to overcome the pressure difference. He concluded that the bypass at Niles Station for an Inline Inspection tool reduced their pressure output and the hill they had to overcome at Mendon station could have been the source of their problem. Shift Lead B1 stated that

[26] PLM – Pipeline Maintenance
[27] This volume calculation was done using the commodity movement tracking line balance reports.
[28] Column Separation- Depressurization of pipe section with oil vaporizing from liquid to vapor state. This normally occurs as a result of excess drain of the pipeline on shutdown and sufficient holding pressures are not held across areas of higher elevations to maintain the fluid in liquid form. The section of the pipe at this stage contains both liquid and some vapor. This condition remains in a pipeline as long as the pressure in the pipeline is less than the vapor pressure of the fluid. And it is typically corrected by increasing the pressure of the pipeline above the vapor pressure of the fluid using pump to pressurize oil in vapor phase back to liquid form.

they should have shutdown a pump and used more pumps at La Porte. Shift Lead B1 went on to say that the pressure in Marshall was virtually zero, amounting to about 4 pounds. When the line was shutdown it was zero pressure at Marshall. Shift Lead B1 maintained that putting in a higher pressure upstream of Marshall should solve the problem. Shift Lead B1 partially attributed the column separation to the drain off that had occurred during the 10-hour shutdown initiated at 6:00 p.m. the previous day.

MBS Analyst B was placed on speaker phone to expatiate, to speak with the Control Center Operation Supervisor. He stated that the distance being covered and the two separate shut downs which had occurred on the line at 5:57 p.m. the previous day and 5:00 a.m. first shut down that day could have caused much suction and losses in the line. After MBS Analyst B explained that there was not enough flow and pressure because of elevation changes and friction losses, it was stated that there was column separation, everything before Mendon Station was intact but downstream of Mendon it was broken and that they needed more pressure upstream of Marshall to overcome the column since Niles Station was on by-pass. The Control Center Operation Supervisor asked him whether they should try starting again and the MBS Analyst B said yes. The Control Center Operation Supervisor told the Shift Lead B1 and the MBS Analyst B his thought in saying "Okay, Well, I guess we can try it again. I guess there's two choices here either consider it a leak, or try it again?"[29]

Shift Lead B1 told the Control Center Operation Supervisor and MBS Analyst B that before they start the pumps again, he thought they should consult the regional management. The Control Center Operation Supervisor asked if they should, and what the procedures states. Shift Lead B1 reviewed one of the control center operation emergency procedures; specifically the MBS Leak Alarm procedure and understood they did not need regional management for their decision. The procedure states:

"*If after 10 minutes an analysis of alarm is not complete, shut down the pipeline and standby for analysis alarm; execute the MBS valid alarm procedure. If MBS fortifies the alarm is false, execute the temporary alarm procedure"*[30].

The Control Center Operation Supervisor asked the MBS Analyst B "what do you call that", and the MBS Analyst B replied "just call it a false alarm" Shift Lead B1 said "okay, false alarm procedure and read:

"If Shift leader, MBS determine that the MBS alarm is temporary, pipeline operator continue normal operations. No pipeline shut downs is required or if pipeline was shut down, resume normal operation"[31].

Control Center Operation Supervisor gave the approval to start Line 6B after the discussion with the MBS Analyst B and shift leads. Shift Lead B1 re-iterated "it is just one of those things where, you have done couple of things. You start Mendon a little too early, didn't get enough pressure there because you came at it a little slower due to Niles

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[29] See Attachment 4: Enbridge Control Center Transcripts
[30] See Attachment 19
[31] See Attachment 18.

Station on bypass, and they drained off 600 cubic meters. They put in 1, 600 cubic meters and still haven't seen it, it meant it is either they packed the line somewhere or else put it on the ground". Control Center Operation Supervisor said "Yeah", then Shift Lead B1 continued by saying "I mean, the MBS alarms states that or they are false due to the column separation" then MBS Analyst B said that when they are static, everything seems to be intact.

Thereafter, Control Center Operation Supervisor said he thought they needed to start again, but was asked by Shift Lead B1 if he thinks they needed to start again, as doing a normal startup, all over" then he said "Well, I don't know. To me it sounds like you need to try it again and monitor it. Like MBS Analyst B said, do it over again. Shift Lead B1 said they will need lots of pressure about 300 to 400 pounds (psig) even before getting to Niles Stations, and that they would be reaching back to him in about half an hour.

At 6:41 a.m. a caller from Bay City called control center, spoke with Operator B3, then asked if they had Line 6B up and running since 4:00 a.m. she said no, that did not happen, because of column separations at Marshall and that the issue was trying to fill it up, but there was no pressures at the station. She told the caller that they were still investigating and that they may possibly have a leak and that they have not sent anybody out yet.

At 7:08 a.m. Operator B1 told Operator B2 they were going to give Line 6B another try, but he asked him whether he was serious, then he responded yes. Operator B1 asked him to open up and have his holding pressure high. Operator B2 said it was already high and he would open up and hold the pressure at 180. According to Operator B2 during an interview stated that after much pumping of oil into Line 6B and calculating the volume they had at Sarnia that things were not right and the differential was great. Operator B2 tried to communicate this to the Shift Leads and the MBS Analyst B that the situation they had was not right, but they had different opinions and the suggestion of leak by Operator B2 was dismissed[32].
See attachment [23]

At 7:12 a.m. Operator B1 received a 2 hour, high priority, volume balance alarm between Griffith and Marshall Pump stations. This alarm indicated that the 2 hour imbalance had exceeded the alarm threshold.

At 7:35 a.m. and 7:36 a.m. Operator B1 received a 5-minute, high priority, material balance alarm, and a 20-minute, high priority, material balance alarm between Marshall and Sarnia.

At 7:37 a.m. Operator B1 received a 5 minute, high priority, volume balance alarm between Griffith and Marshall Pump station.

[32] Human Factor Interviews of Operator B2 on January 31, 2012

At 7:38 a.m. Electrician B after being informed by PLM shop Mechanics at Marshall about the problem on Line 6B[33] called and spoke with Operator B3. He stated that he just got a message and wanted to know whether Line 6B was shut down because of Marshall, but she said not because of Marshall instead they had a column separation and wanted to fill up the column there, and they shut down the pipeline but are trying to start it up again to fill it up.

At 7:42 a.m. Operator B1 received a 20 minute, high priority, volume balance alarm between Griffith and Marshall.

At 7:46 a.m. Shift Lead B1 called Control Center Operation Supervisor told him that Line 6B had been running for 10 minutes with a pressure of three psig on the Marshall discharge and that there was not enough pressure to close the column separation. They discussed that the Griffith station was maxed out in power and that they were short of a pump at La Porte Station due to maintenance and that the Niles station was bypassed and unable to run because of the In-line inspection tool. They estimated needing 120 pounds (psig) just to move from Mendon to Marshall which they believed they could manage; however, they needed 350 pounds (psig) to overcome frictional loss and elevations and may not have enough power. In the end it was decided that Shift Lead B1 would call the Control Center Operation Supervisor later.

At 7:48 a.m. Shift Lead B1 asked Operator B1 if they could start a unit at La Porte, but was told no. He then asked if they could run any of the remaining three during emergency situation and was told no, however, it could be started if Shift Lead B1 wanted it. Shift Lead B1 asked if there was an instruction not to start it, but Operator B1 said no, it was due to power problems and for that reason they only gave them one unit to run. Shift Lead B1 authorized pump unit U-4 to be started and called for 320 to 330 psig.

At 7:50 a.m. Operator B3 console team mate to Operator B1 who was busy operating other lines, called a Power Supervisor on behalf of Operator B1 on Line 6B. She stated they were having problems on the line in not getting the columns together at Marshall then asked if there is any way they can get more pressure from the pumps at La Porte. According to the SCADA data log report, no additional pump was started from La Porte station during the second start up.

At 7:51 a.m. Electrician B from Marshall Station placed a second call to the control center and spoke with Shift Lead B1. The electrician stated that he received some information about the problem at Marshall Station concerning low pressure and has walked the station for leaks but found no oil on ground. Shift Lead B1 stated that the control center had figured out that they did not have enough upstream pressure to overcome the column separation. And that they have to get another pump at La Porte to continue Line 6B running again[34]. Electrician B then said if they needed his assistance he should be available at the Marshall Station.

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[33] See Attachment: 27 - Electrician B Interviews Transcripts on July 29, 2010

[34] They could not proceed running the pipeline because they did not get more power to continue. At the same time Operator B1 supposes to be the individual managing the power issues.

At 7:54 a.m. Shift Lead B1 called Control Center Operation Supervisor told him they were just shutting down and did not have enough power to get the column back together. Shift Lead B1 said they shall be calling some field personnel to get some power by making more units available to get Line 6B running.

At the same time 7:54 a.m. Operator B1 said to Operator B2 the terminal operator "So close it, all my pumps are down, so I don't care. You can close off whatever because it's not going to take me down, that's for sure". And since it does not matter and they should close off whatever pump because it is not going to change anything. Operator B1 stated that there was not enough power even to get oil into Marshall. Operator B2 said he has never seen this problem before and that it was interesting. Operator B2 stated that the situation looked liked a leak, and Operator B1 stated that they could pump as much as they wanted but could never over pressurize the pipeline. Operator B2 stated that eventually the oil has to go somewhere. Operator B2 said that it seemed as if there was something wrong about the situation. Operator B2 said to Operator B1 "whatever, we're going home and will be off for few days". Operator B1 stated they were not going to try this again, not on their shift[35].

At 7:56 a.m. Operator B1 called the In-line inspection tool tracker and told him that Line 6B was shut down again and that he was leaving in 20 minutes. The operator said he did not have enough power upstream with Niles Station bypassed and out of operation.

At 8:02 a.m. Operator B3 called one of the line workers telling him they need to get off Line 6B because they were going to start it up. Following this at 8:08 a.m. Operator B1 called Operator B2 told him they were going to give Line 6B another try but he asked him whether he was serious then he responded yes. Operator B1 asked him to open up and have his holding pressure high. Operator B2 said it was already high and he would open up and hold the pressure at 180**.** However, the SCADA data logs and trends showed that there was no third attempt to start Line 6B.

At 8:17 a.m. Technician B called Operator B1 and told him he would be at La Porte Station in five minutes. Operator B1 told him they figured out they needed another unit at La Porte since Niles Station was bypassed, they could not get enough pressure to get oil into Marshall. Technician B told him he had three out of four pumps available, Operator B1 replied that any of the three online would work.

Shift C July 26, 2010

At 8:28 a.m. Technician B out of La Porte on Line 6B called control center, spoke with Operator C1 about the operators need for more pump at La Porte. Operator C1 stated just haven started the shift and would talk with the Shift Leads or whoever to know what was happening. Technician B said he will remain at La Porte and stated there seems to have been a vibration shut down on unit U-1, which he had re-set and made available.

[35] See Attachment: 4 - Enbridge Control Center Transcript at 07:54 a.m.

At 8:36 a.m. Shift Lead C2 called Control Center Operation Supervisor, and left a voicemail message that they needed his attention urgently because at La Porte they required power and have problem moving oil from Mendon into Marshall, and temporarily required two units for an hour from La Porte.

At 8:46 a.m. Shift Lead C1 asked Operator C1 what was going on in his console, in turn Operator C1 inquired from him what the plan was for La Porte Station because they cannot run two pumps at the station. The Shift Leads asked him about the sequence he normally follow during startup and Operator C1 stated normally bypassing every other station along Line 6B.

At 9:49 a.m. Shift Lead C2 called Electrician B at Marshall and told him they started up on July 26, 2010 but there was column separation at Marshall and they could not get the line filled. When the control center looked into the trends from the previous day they saw that there was adequate pressure along Line 6B up to the shutdown on Shift A. However, beginning around the time of the shutdown, pressure at Marshall went to zero and never came back up. Electrician B replied that when he got to Marshall Station the pressure was initially 4 psig and later went to zero. Shift Lead C2 asked the electrician if he had seen anything at the station, but Electrician B, said he had checked every location within the station and found no leaks. Shift Lead C2 said since he has checked that they will reach his management in case walking Line 6B was required.

At 10:16 a.m. Shift Lead C2 called and reached the Regional Manager, told him the problems they were having on Line 6B, and the column separations at Marshall and not being able to put it together, how they have started and shut down two times already but couldn't fill the pipeline. He described to him about the entire scheduled shut down the previous day while going to Stockbridge, startups, and shutdowns on July 26, 2010, while going to Sarnia, which they only got up to 4 psig and after calculations they found out that over 600 cubic meter had drained off during the shutdown. However, after every effort, they couldn't bring the column separation back together at Marshall, they got Electrician B at Marshall who checked out the station and reported everything was in good condition. Shift Lead C2 stated they reviewed the pressures at the shut down the previous day, and noticed that the pressures right when the pumps were shut down, the pressures on the suction and discharge went to zero at Marshall, and whenever pressures at suction and discharge goes to zero you take a look around the station because something must be wrong. Whenever the suction and discharge goes to zero you will be checking for a leak, it means something happened at the station, and if all three transmitters went to zero at the same time. Shift Lead C2 stated "at this time we are kind of at lost, and are checking at more numbers", then said to the Regional Manager "But I don't know if you guys need to check out some of the pipeline upstream and downstream of Marshall". The Regional Manager asked him "do you want us to check" and stated that "I wouldn't think so that it is right at Marshall, it seems there is something else going around either with the computer or the instrumentation". And also said "you lost column and thing went out of hand. Do you want us to check; right now I am not convinced, we have not had any phone call, if it is a rupture someone is going to notice that and smell it".

Shift Lead C2 said it means they would just continue to look into things at the control center, and if they cannot make sense out of the numbers, they would have to call the regional management back. The Regional Manager said the control center should call them again but he agreed if they wanted to start the pumps again (ready to go again) "if it look like the numbers are fitting". And that they have his approval to start again (go again). And they should give them a call if they definitely decide to have someone walk the line, because they supposed to have heard by now[36].

Shift Lead C2 asked Regional Manager whether the Marshall area is populated and he stated that though the Marshall area is not much populated, there are always people driving around the area.

At 10:22 a.m. Operator C1 came back with analysis of the delivery valve closure at Stockbridge during shutdown on July 25, 2010 which Shift Lead C1 asked him to verify. He told Shift Leads C2 & C1 that he found the valve and it seems to have been closed during Marshall Shutdown, it was in travel when they issued the pump stop command and all these happened at the same time.

At 11:01 a.m. Operator C1 explained to the Shift Lead C2 that Operator A1 issued the command to shutdown Marshall Unit when it went to zero. He stated that Operator A1 shutdown Niles Station at 5:57 p.m., Mendon Station at 5:58 p.m. and Marshall at 5:58 p.m. at almost the same time; there was no particular sequence of shutting down the pipeline.

At 11:17 a.m. the Enbridge control center Shift Lead C1 received a call on the emergency line from a consumer energy gas utility employee reporting of oil on the ground downstream of the Marshall station. The caller stated the oil was into the Creek and believed it belonged to Enbridge Energy pipeline. That there was lots of oil and that they got 20 gas leak calls and had tried to walk the line to see where the pipeline broke. Then stated the Creek color was black and he was located at 27 Southern Division Drive also called South Kalamazoo. The caller then asked Shift Lead C2 if they had local personnel and he responded yes. The caller re-iterated being located at south of Marshall. Shift Lead C2 stated that the control center would be giving the Enbridge Energy field personnel a call.

At 11:20 a.m. Shift Lead C2 called the Chicago Regional Manager and told him they received a call from a Consumer Energy employee who said they had received calls from around two miles South of Marshall, near Highway 27 and Division Drive and that he had discovered oil on the ground. Then the Regional Manager asked whether it sounded like it was their pipeline, the Shift Lead C2 concurred yes. Shift lead C2 stated that they were isolating as much as they could. The location was estimated to be between milepost 608 and 609 given that the Marshall Station was located at milepost 607.

At 12:54 p.m. Shift Lead C2 called Regional Manager told him he received a call from the field crew that there was oil on ground about quarter to half a mile downstream

[36] Enbridge Control Center Transcripts at 10:16 a.m. on July 26, 2010

of Marshall Station. The Regional Manager then said he will be the Incident Commander for July 26, 2010, and some other person shall take over the next day, and then agreed that Shift Lead C2 and the control center personnel should call the police and follow the Enbridge emergency response procedures.
See attachment [4 & 5]

E. <u>Pipeline Operations and SCADA Control</u>

According to Enbridge, pipeline operators are responsible for starting and shutting down of various pipeline assigned to them at their console in a particular shift and at the same time assists their console pod-mates.

During start up of pipeline(s), operators' calls on the terminal operators to start the booster pump(s) which they need after they have sent commands to open line required valves and stations pumps between the terminal(s) and stations they are scheduled to operate. Also during shut downs the pipeline operators' call on the terminal operators to shut down the booster pumps while they send commands to stop mainline pumps and close designated mainline valves.

At start up and shut down operations, the operators through the means of computer with SCADA control capabilities send commands to the respective pumps and valves in the field. In addition to a separate computer database that houses the operation procedures and for administrative communications not shown in the figure below, the simulator console comprises three different monitor screens showing several computer window displays for various pipelines. These screens display information such as the pumps, MBS, pipelines, unacknowledged alarm panel, historical SCADA data and valves displays (see figure 2). But a typical console at the time of Line 6B pipeline rupture incident had up to eight smaller sized monitors per console (see figure 2a).

Figure 2: Simulated Training Console; operations SCADA screens displaying simulated Line 6A & 6B on February 1, 2012, Source: NTSB.
See Appendix 2

Figure 2a: Typical Similar Operators Console on July 25 & 26, 2010 at the control center, Source: Enbridge.
See Appendix 2a

An Enbridge pipeline operator on this simulated training console (figure 2) controls Line 6A & 6B. The operator starting up and shutting down any of the pipeline has to monitor each of these screens from left to right: first monitor comprises the two tanks screen displays on top, and MBS screen display at the bottom, the second monitor comprises two pipelines Line 6A & 6B screen display on top and an unacknowledged alarm panel at the bottom, and the third monitor comprises two Line 6A & 6B valves screen on top and the historical SCADA data screen at the bottom.

Figure 3a: Main Menu panel on February 1, 2012, Source: Enbridge Energy (NTSB: IR 351)
See appendix 3a

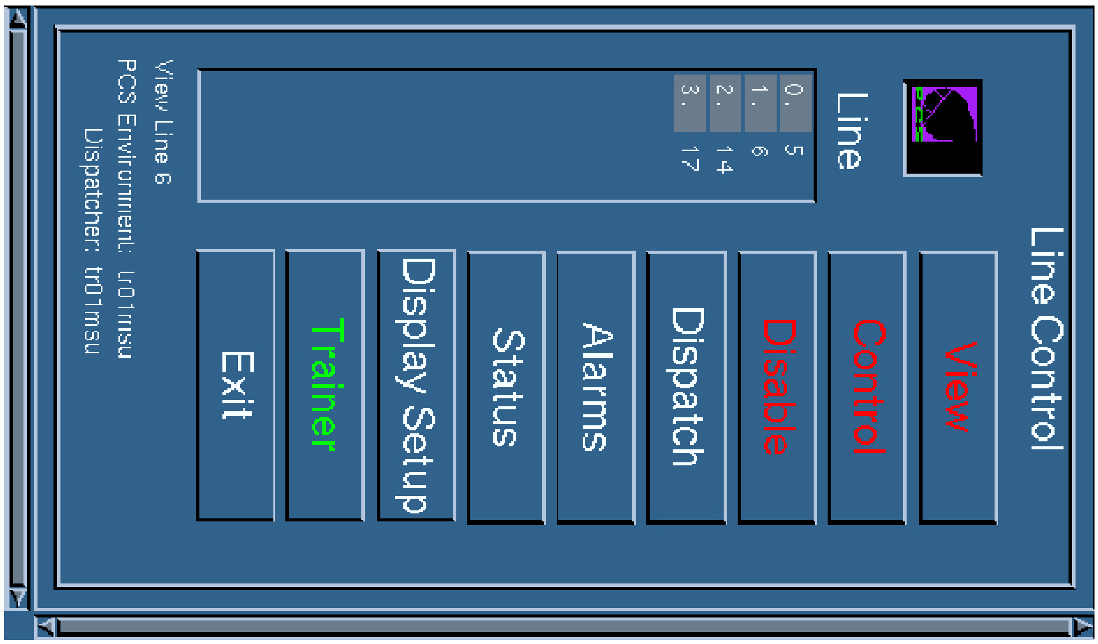

Figure 3b: Line Control Panel on February 1, 2012, Source: Enbridge Energy (NTSB: IR 351)
See Appendix 3b

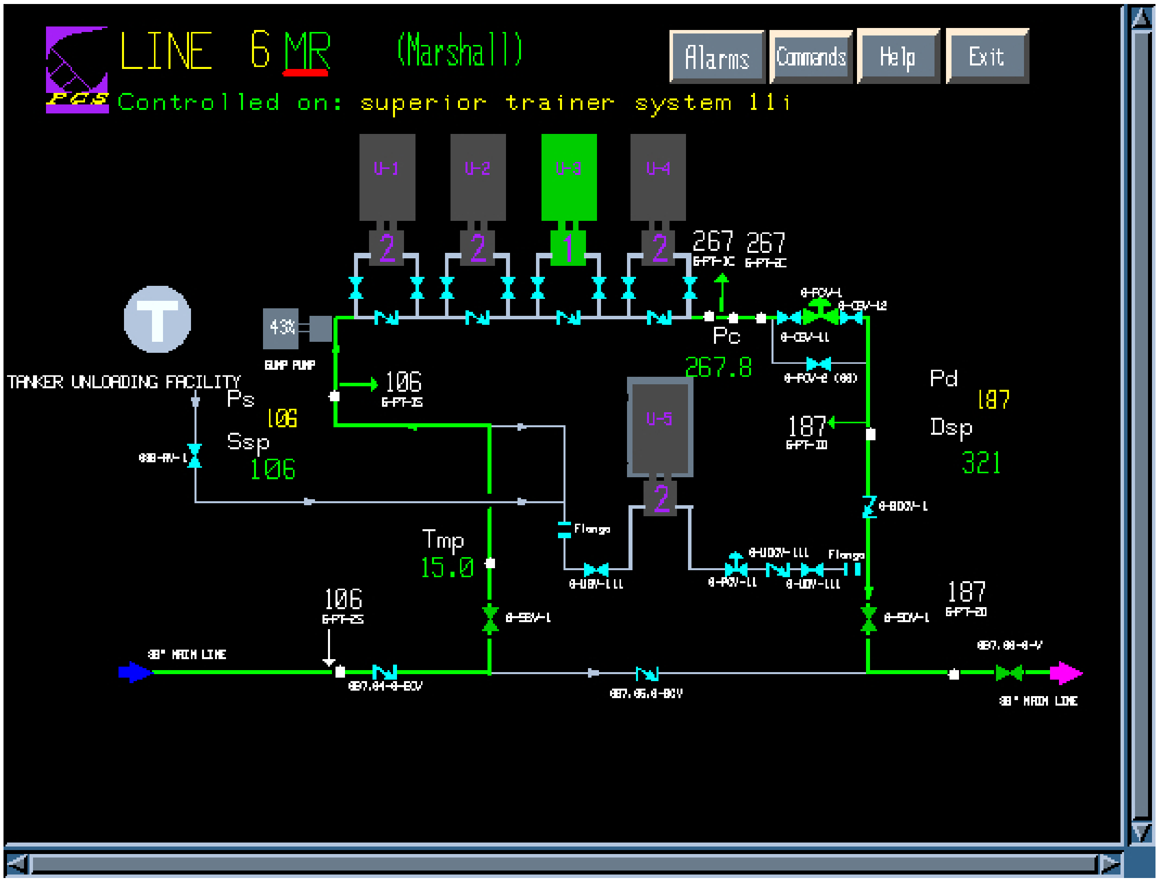

Figure 4: Simulated Marshall Station with pump unit-3 running, on February 1, 2012, Source: Enbridge Energy (NTSB: IR 351).

See Appendix 4

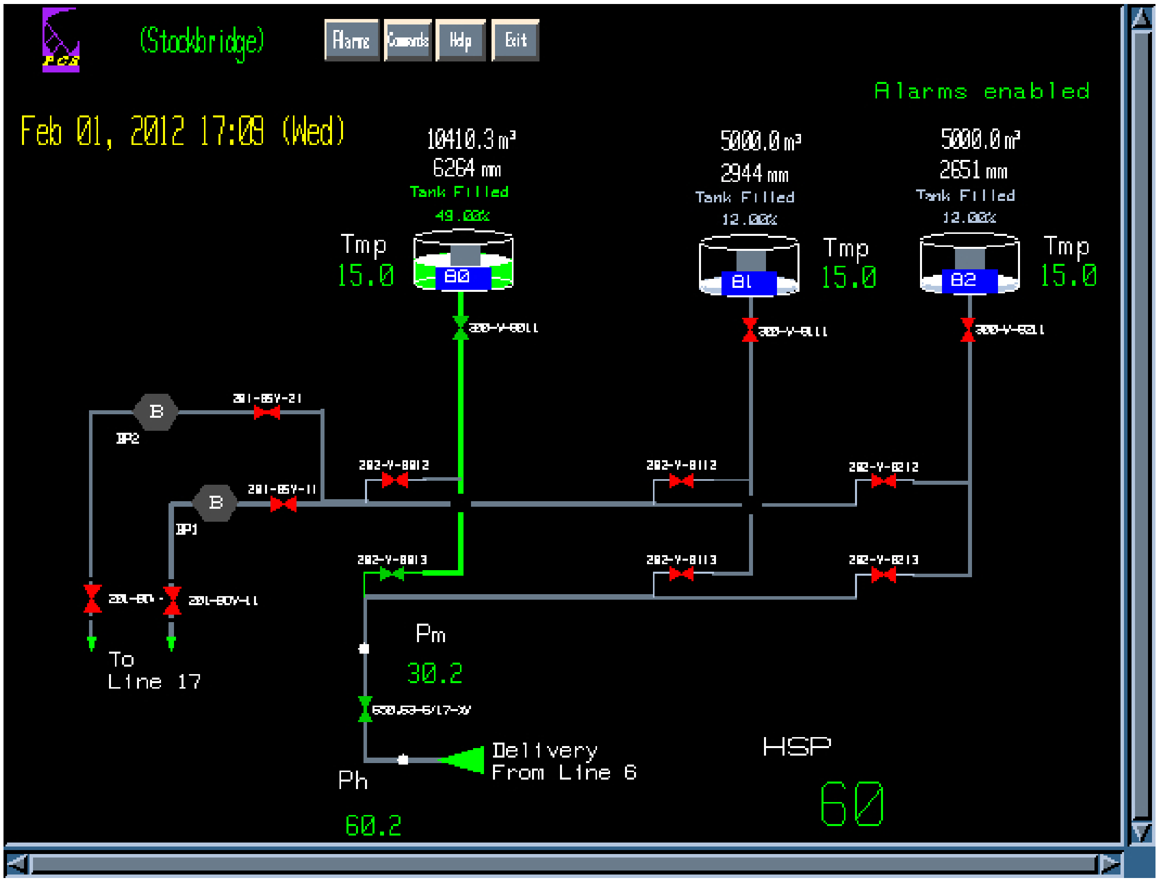

Figure 5: Simulated Line 6B Stockbridge tank farm (terminal station) display on February 1, 2012, Source: Enbridge Energy (NTSB IR -351)
See Appendix 5

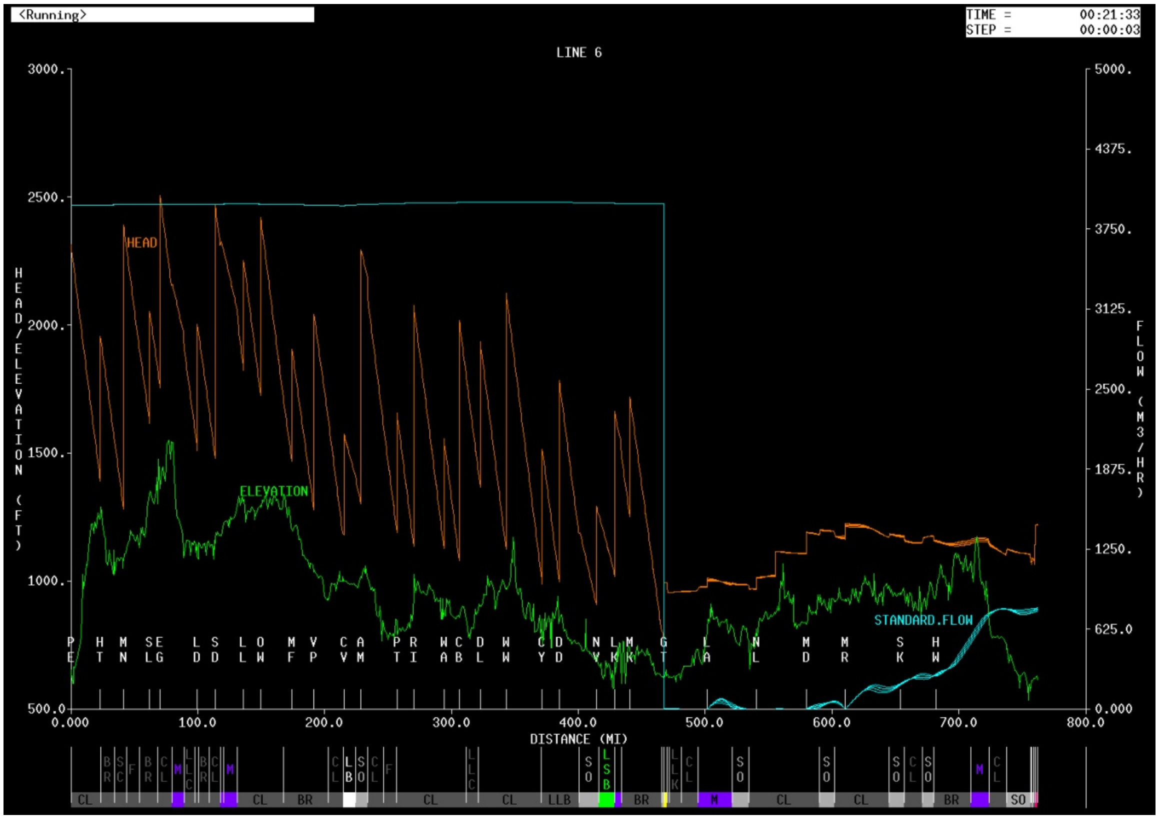

Figure 6: Offline simulated Line 6B shutdown MBS display on February 1, 2012, Source: Enbridge Energy (NTSB: IR 351).

See Appendix 6

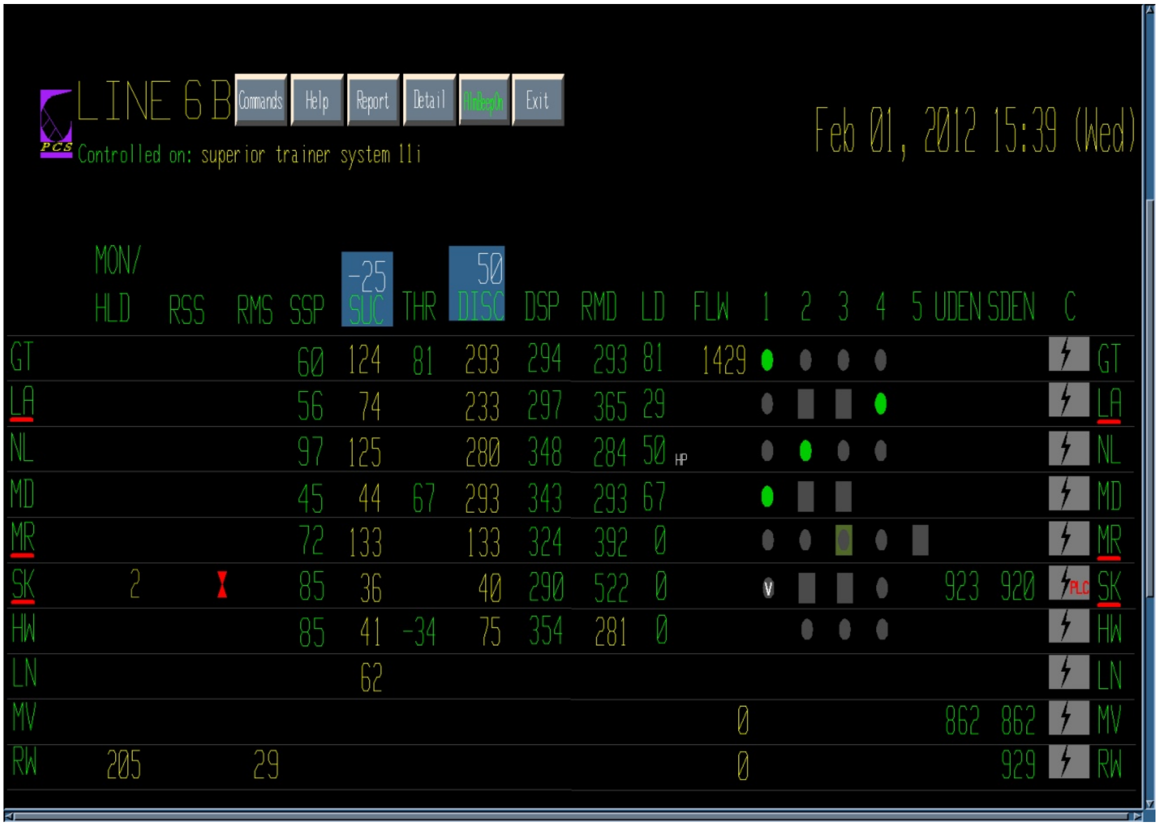

Figure 7: Simulated Line 6B pipeline display leak, on February 1, 2012, Source: Enbridge Energy (NTSB: IR 351).
See Appendix 7

Figure 8: Simulated unacknowledged alarm panel on February 1, 2012, Source: Enbridge Energy (NTSB: IR 351).
See Appendix 8

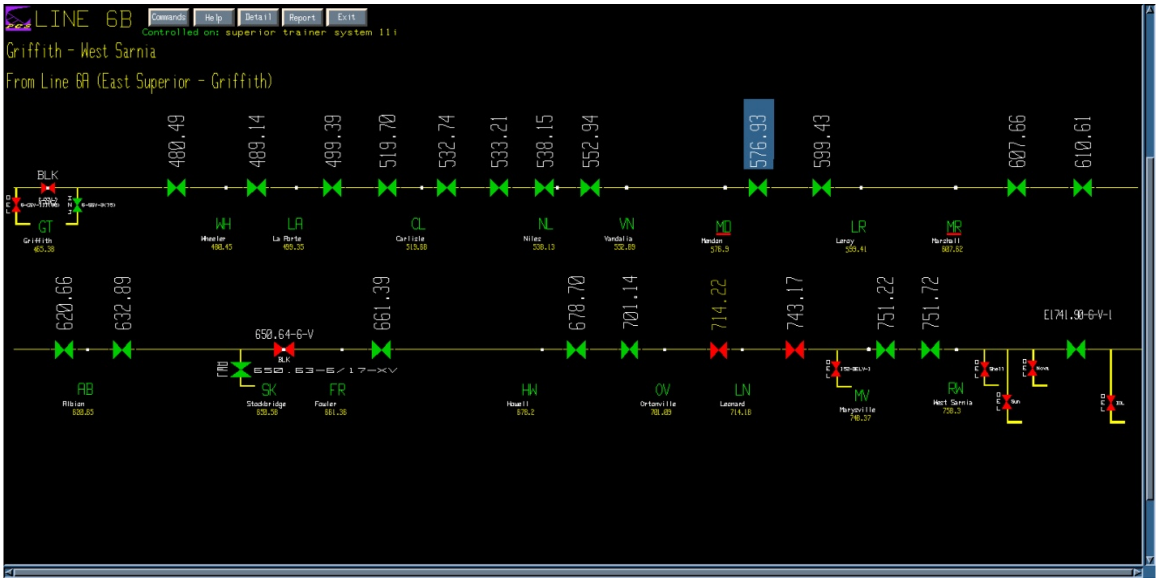

Figure 9: Simulated Line 6B valve display from Griffith to West Sarnia on February 1, 2012, Source: Enbridge Energy (NTSB IR-351).
See Appendix 9

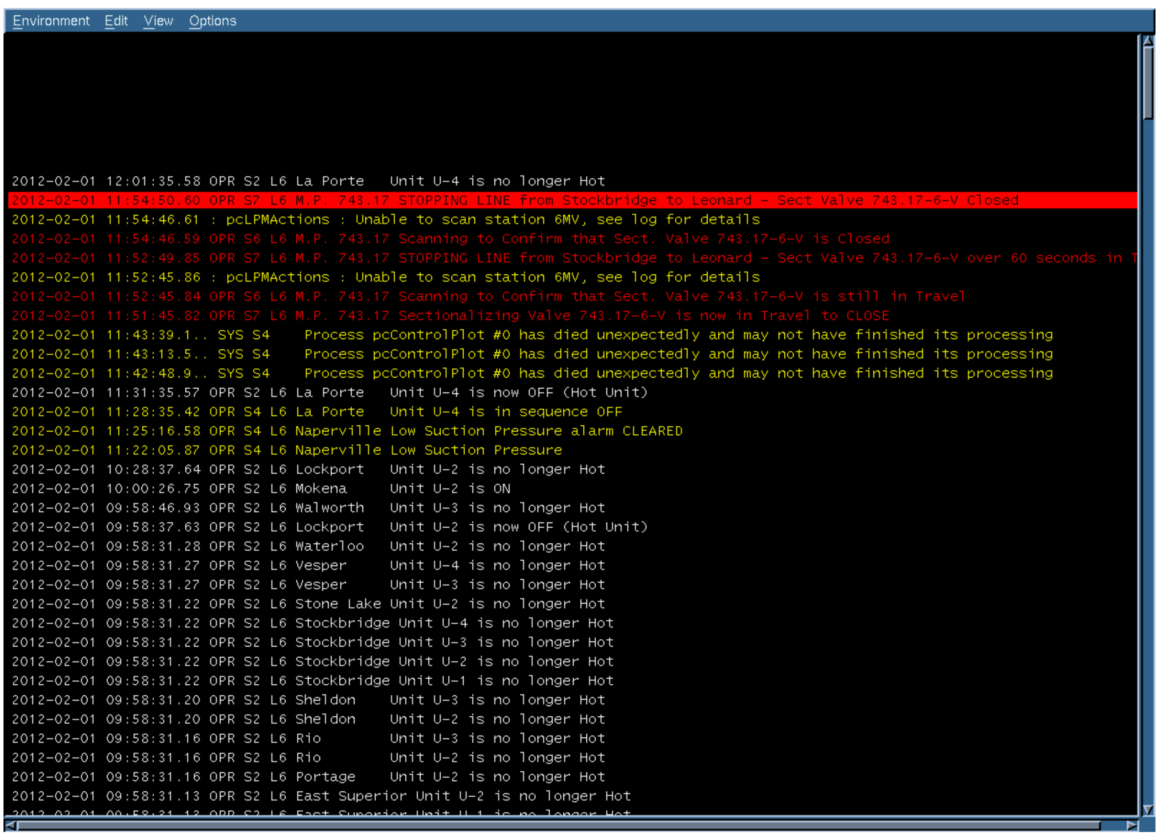

Figure 10: Simulated historical SCADA data display for console on February 1, 2012, Source: Enbridge Energy (NTSB IR -351).
See Appendix 10

F.0 Procedures and Operations

F.1 The 10-minute rule

The 10-minute limit is required in several operations procedures and was also utilized in the control center MBS leak alarm, and suspected column separation procedures and is referred to in the control center as the "10-minute rule."
The 10-minute limitation was first adopted by Enbridge[37] following a March 1991 accident that resulted in a 40,500 barrel release of crude oil in Grand Rapids Minnesota that polluted a tributary of the Mississippi River and resulted in clean up costs of $7.5 million. In the 1991 accident, the Edmonton control center had continued to operate the 34-inch line 3 for over an hour after seeing an increase in pump power at 12:20 p.m. (CST). Believing that the condition was related to column separation and instrument error, the control center continued to pump into the ruptured line until approximately 1:31 p.m. when the line was shut down. The 1967 segment had failed due to fatigue cracks located in the heat affected zone at the toe of the double submerged arc weld.

As part of Enbridge's stipulation to PHMSA, a revision to the Operation Maintenance procedures manual was adopted by the control center stating that, "If an operator experiences pressure or flow abnormalities or unexplainable changes in line conditions for which a reason cannot be established within a 10-minute period, the line shall be shutdown, isolated and evaluated until the situation is verified and/or corrected." As part of the procedure the operator was required to review historical line data to check for conditions that may indicate a leak. The procedure further noted that neither a pump configuration nor rate should be changed until operator is reasonably certain that leaks actually exist or within 10 minutes, whichever was shorter. During the 2010, accident on Line 6B the control center had identified areas where more power could be added to increase pressure and volume into the pipeline. Additional pumps at the La Porte station had been identified for possible operation; however, a start command issued by the control center was unsuccessful and the additional pumps were not put into service[38].

F.1.1 Operations

According to Enbridge during Line 6B operation the operator has at least eight screens and panels (figure 2a, 3 to 10) in addition to the computer system for procedures database available to them in the control of the pipeline. While the pipeline is on start up, in operation and on shut down, if the operator receives an MBS alarm and any other system alarms from medium to high priority between S4 to S8, it registers on the unacknowledged alarm panel and the historical SCADA data screens and remains at those locations until acknowledged by the operator. After these categories of alarms are acknowledged it remains on the historical SCADA data screen but it disappears from the unacknowledged panel. However, there is another low priority alarm of S2 to S3 which does not appear on the unacknowledged panel but registers and remain within the

[37] Enbridge was operating as Lakehead Pipe Line Company at the time
[38] Attachment: 32 Source of 10-minute rules

historical SCADA data panel. Also when an MBS alarm clears, a message is sent to the operator.
According to Enbridge from medium to high priority alarms are audible and visibly colored differently, while the low priority alarm does not display any of these characteristics.
See Attachment [10] [39]

F.2 <u>Operations</u>

F.2.1 <u>Suspected Column Separation and Abnormal Operating Conditions (AOC)</u>

According to Enbridge approved suspected column separation procedure which states that "a pipeline operator is to *notify the shift lead whenever a suspected column separation alarm is received, but if the column cannot be restored within 10 minutes*, then *shutdown the specific pipeline, sectionalize*[40] *the line valves and isolate the pipeline*. This is followed by the operator *executing the abnormal operations condition reporting procedures*. This also requires that the *shift lead execute the emergency notification procedure*, and *if field personnel locate a leak*, the *shift lead should initiate the confirmed leak procedure*, and *field personnel verification procedure*. *If field personnel do not locate a leak*, then a *permission to restart the line may be granted only by the Pipeline Control on-call designate*".

Enbridge Energy defined Abnormal Operating Conditions as: *a condition that may indicate a malfunction of component or deviation from normal operation that may; indicate a condition exceeding design limits, or result in a hazard(s) to persons, property or the environment.*

The lists of AOC's stated by Enbridge Energy are currently the following:

- Pipeline Obstruction
- Suspected Overpressure
- Suspect leak
- Confirmed Leak
- Site Emergency Alarm
- Suspected Column Separation
- Communication Failure
- SCADA Field Equipment Malfunction
- Station Lockout
- Valve Malfunction

Attachment [37]

[39] Attachment 10: Enbridge Control Center Recorded Simulated Demo on February 1, 2012
[40] Sectionalize means closing off specific valves to stop backflow into a section of a pipeline.

Operator A1 on July 25, 2010 from his console with simultaneous running of pipelines 6A, 6B, 3 and 17, on shut down of Line 6B after initiating a stop pump command at approximately 5:55 p.m. at Menden station noticed a reduction in pressure, reacted with an increased pressure at Stockbridge the delivery location to avoid column separation and excess draining, at Marshall within seconds of sending pump stop command received a 5-minutes MBS alarm which according to the operator during interview on July 28, 2010 stated it was audible, visibly red colored, and high priority alarm of S8, but according to the historical SCADA data log received from Enbridge it registered as S6. Operator A1 reported to the Shift Lead A2 who called in MBS Analyst A for analysis. Operator A1 after completing the shutdown received a call from MBS Analyst A who stated there was column separation, which both agreed was at Marshall. Operator A1 said the column would remain there until the start up at 4:00 a.m. the next day. The 5-minutes MBS alarm was said to have cleared from the alarm panel by itself. Neither Operator A1 and A2, nor MBS Analyst A investigated the cause of the column separation.

According to Enbridge a typical MBS leak screen Operator A1 could have seen is as in figure 6 but the operators are not adequately trained to conduct analysis from it, it is the responsibility and expertise of the MBS Analyst. The MBS screen display the; elevation, pressure, and standard flow. But Operator A1 and Operator A2 at the consoles had other sources of information on Line 6B screen displays to review the cause of the stated column separation, such as the historical SCADA data (figure 10), and Line 6B pipeline displays. According to Operator A1 interviews the historical SCADA data display was not reviewed because the operating conditions were interpreted as not being abnormal.
See Attachment [10]

According to Enbridge AOC procedure after an operator *notifies the shift lead*, the operator is required to *enter the AOC or MBS indicator activated into a facility management database, normally referred as FACMAN*[41] by Enbridge. Operator A1 stated in an interview to have failed to document these because the conditions were not seen as abnormal, but verbally informed the in-coming Operator B1 about the occurrence of MBS alarms and Niles Station bypass. However, 5-minutes MBS alarm was created in the FACMAN[42] during shift A, but no other AOC's that occurred was entered. According to Operator A2 during an interview she stated being pre-occupied with a different project during the shift while Operator A1 (mentee) was operating the pipeline. Operators A2 further stated that "I have complete confidence in Operator A1 ability to operate the pipeline as well or even better than I can"[43].
See Attachments [1, and 12]

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[41] FACMAN: This is a database available to the operators to record all MBS and abnormal operating conditions encountered during shift period.
[42] Attachment 38: FACMAN created on July 25 & 26, 2010
[43] See - Operator A2 interview transcript on July 28, 2010

On July 26, 2010 at 4:00 a.m. Operator B1 observed Valve 632.89 with unknown state due to loss communication as he proceeded to start Line 6B. He told Shift Lead B2 that the valve should not have been operated, but he sent an open command to it in case it decides to close back. Shift Lead B2 acknowledged his actions as positive. The status of this valve constituted an abnormal operation conditions with communication fail, had intermittently remained in Enbridge system since July 22, 2010 and did not clear until August 4, 2010. None of the operators that operated Line 6B through those dates created a FACMAN[44] for it.
See attachments [6, and 39]

Operator B1, B2, and B3 started Line 6B, received MBS leak alarms. Operator B1 notified the Shift Lead B1, B2 then Shift Lead B2 assessed it with MBS Analyst B who attributed it to column separation which was another abnormal operation conditions, they called it temporary MBS alarms[45]. Shift Lead B2 followed the draft suspected column separation procedure going over one hour before shutdown of Line 6B.

The draft column separation procedure in contrast to the approved version stated above[46], in addition includes a new segment that states; *"if a starting up into a known column separation; pipeline operator notify shift lead, calculate the amount of volume drained, and calculate a restoration time to restore the column separation*. Then shift lead should *confirm calculated restoration time with Pipeline Operator*, request operator to *start up into the column separation starting the 10 minutes rule when the calculation restoration time expires. If the column cannot be restored under the above conditions,* request the *operator to shutdown, sectionalize and isolate, and execute the emergency notification procedure*[47]". This draft procedure was used in May 2010 and was pulled by Operator B3 and offered to Shift Lead B2. The draft procedure contains a section requiring the *calculation for the amount of volume required to fill up the column*. To do this Shift Lead B2 used the commodity movement tracking line balance reports in an attempt to quantify how much volume was lost during the shutdown and start up in order to calculate an expected time to bring the column together. This section of the procedure was followed after ten minutes which time the column separation was not filled in and continued until the pipeline first shutdown at approximately 5:00 a.m. for further analysis and communication with Control Center Operations Supervisor.
See Attachment [14 and 15]

The operation personnel did not consider or recorded these MBS alarms and column separations as abnormal operating conditions and neither were these considered as leak. The AOC procedure[48] was therefore never followed and so leak triggers were never considered.

During a latter interviews Operator B1 stated never reviewing pipeline trends (figure 6 & 7) and the historical SCADA data (figure 10) to know what was going on

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[44] Attachment 39: Valve 632.89 Communication Fail without FACMAN (facility management)
[45] See Attachment 18: MBS Leak Alarm –Temporary Alarm
[46] F.2.1 paragraphs 1
[47] See Attachment 17
[48] See Attachment [12]

with Line 6B due to overwhelming workload of simultaneous operation of other lines 6A, 3, and 17 at his console, but however, expected that the Shift Lead B1, B2 and MBS Analyst B should have looked at them since they were involved in investigating the conditions. Shift Lead B1 stated not being involved from the beginning of the diagnosis of Line 6B problems and had no knowledge of the use of a draft procedure but was involved in the second start up and communicating the conditions to the Control Center Operation Supervisor. Shift Lead B2 stated they reviewed the trends and the historical SCADA data, but only investigated back to the beginning of their first pipeline start up at 4:00 a.m. and never extended this search to the period covering shutdown from the previous day[49] to have seen the leak triggers at Marshall.
See Attachment [16]

F.2.2 <u>Column Separation at Rupture Location, Marshall - Michigan</u>

According to Enbridge in the 12 months prior to the July 17, 2009 of self imposed pressure reduction there were no MBS alarms attributed to column separations on Line 6B. However, in the 12 months following the self imposed pressure reduction there were three MBS alarms attributed to column separation. And the location of the column separations was downstream of Stockbridge Terminal for each of the alarms. The table below lists the date of occurrence, MBS Alarm Section, Alarm Type and Column Separation location for each of the MBS alarms.

MBS Alarm History, July 17, 2009 - July 17, 2010

Date	MBS Alarm Section	Alarm Type	Column Separation Location
27-Jun-2010	MRRW	5-Min, 20-Min	Downstream Stockbridge, Leonard Valve Site
28-Apr-2010	MRRW	5-Min, 20-Min	Downstream Stockbridge
18-Oct-2009	MRRW	5-Min, 20-Min	Marysville Area

Table 1: Summary of MBS and Column Separation alarms from Marshall, Source: Enbridge

From the above summary as presented, Marshall, Michigan has not typically been noted for column separation. Notwithstanding, at times according to Enbridge when Line 6B was shut down, column separations have occurred downstream of Stockbridge between Howell and Sarnia. And since column separation is said to occur due to

[49] See Human factor interviews on January 31, 2012

elevation change, Marshall Area at the same time does not have any appreciable elevation changes at that location[50].
See Attachment [13 and 20]

G.0. Material Balance System (MBS) Support and Analysis

G.1. MBS System

Enbridge uses a computation pipeline model (CPM) for detecting leaks on Line 6B. The type of CPM used by Enbridge is known as a Real Time Transient Model. The model is comprised of computer based hydraulic model that includes all of the critical hydraulic details of the pipeline. Design of this includes knowing information of the pipeline such as pump station parameters, pipeline inside diameters, lengths of pipe as it changes, elevations, locations of transmitters and line-valves mileposts[51]. This hydraulic model is connected to the Enbridge Commodity Tracking System and SCADA system to import the actual operating pressures, flows and crude oil properties within the pipeline.

The material balance system uses this information to calculate; validate the flows and pressures on the system. The material balance system compares its expected flows and pressures to those reported through the SCADA flow meters and pressure transducers. If the material balance system finds a discrepancy in the flows then it generates an alarm. The MBS system utilizes three separate thresholds of detection. These are a 5 minute[52], 20 minute[53] and 2-hour alarm[54]. The flow imbalance threshold is larger for each corresponding time limit. At 5-minutes the flow imbalance must be approx. 50 m^3, at 20 minutes the flow threshold is approx. 100 m^3 and at 2-hours the flow imbalance must reach approx. 300 m^3 in order to trigger the alarm.
See Attachment [21]

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[50] See Attachment: 20 – Elevation Changes
[51] See Attachment 22 – Interviews of Enbridge MBS Engineer
[52] See Figure 11
[53] See Figure 12
[54] See Figure 13

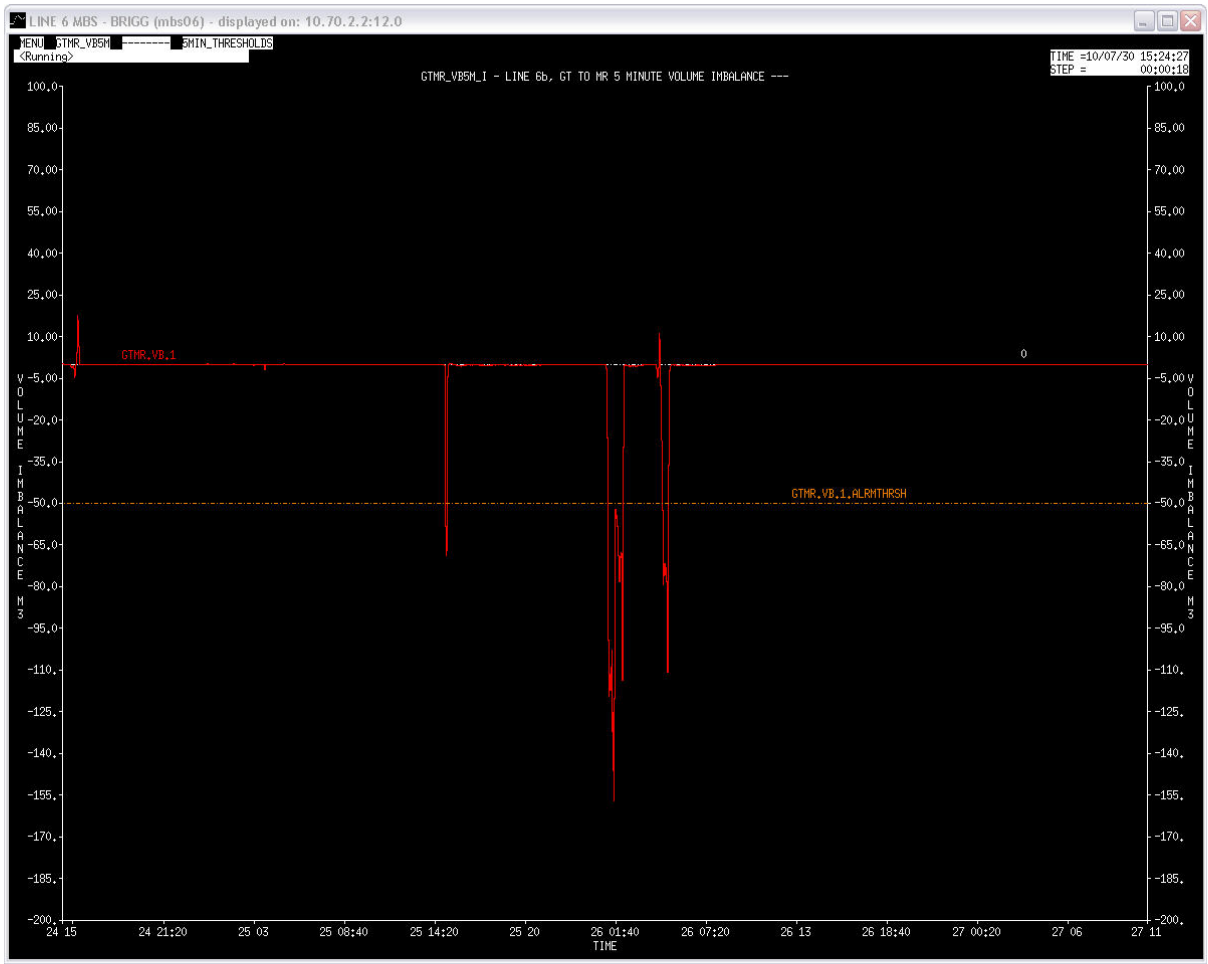

Figure 11: Shows Griffith to Marshall 5-Minutes Alarm Imbalance, Source: Enbridge Energy.

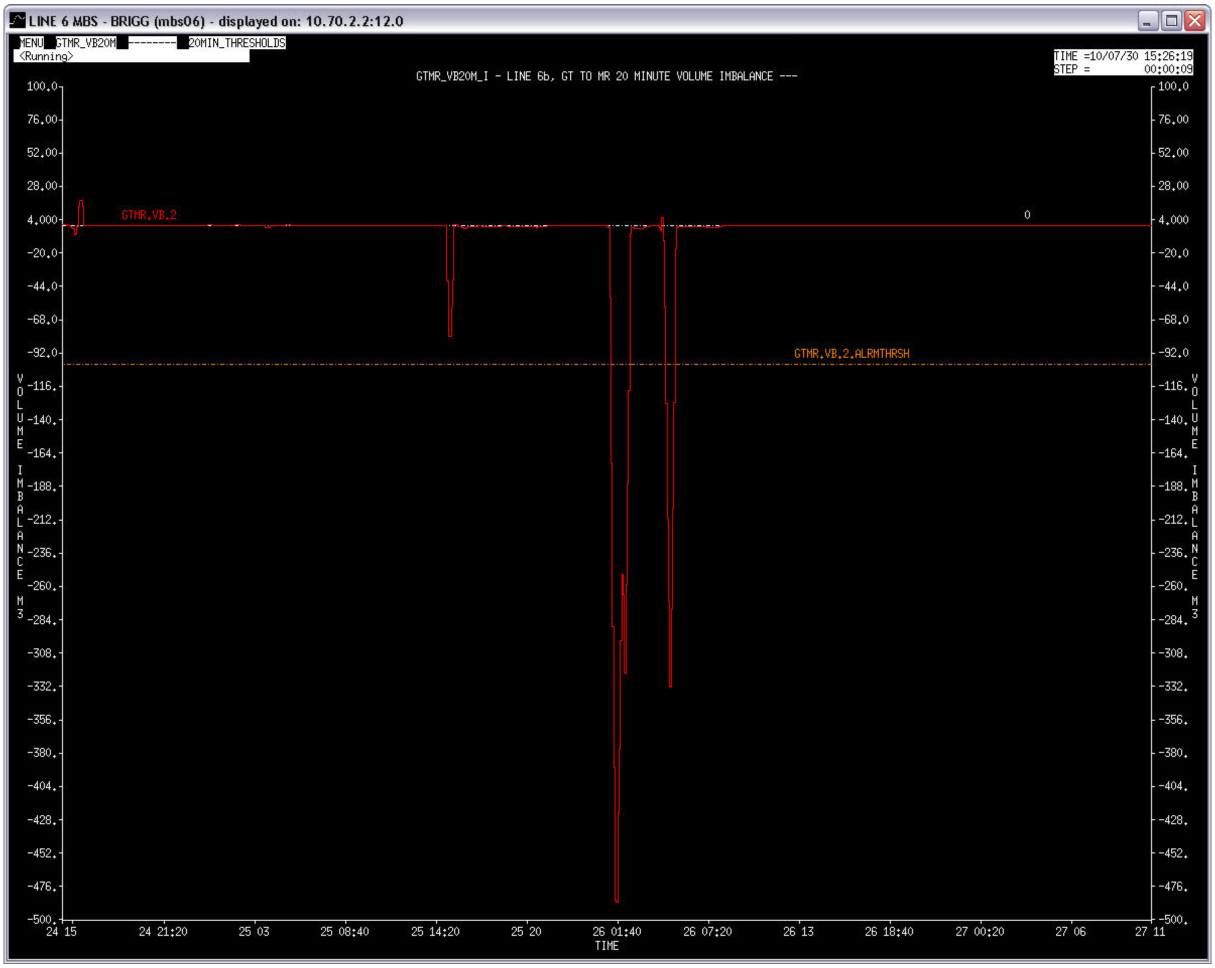

Figure 12: Shows Griffith to Marshall 20-Minutes Alarm Imbalance, Source: Enbridge Energy.

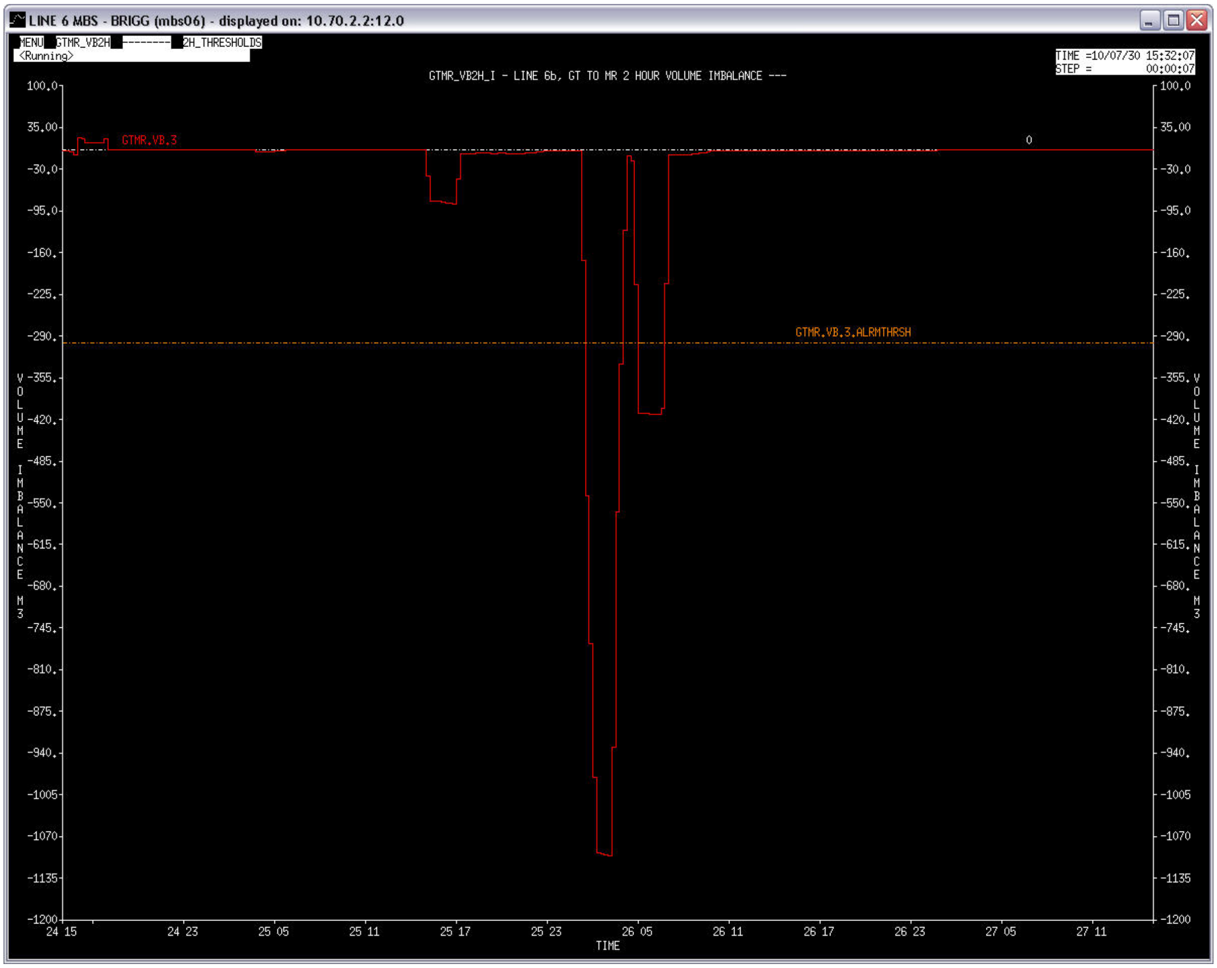

Figure 13: Shows Griffith to Marshall 2-Hour Alarm Imbalance, Source: Enbridge Energy.

The CPM in use by Enbridge for leak detection is based on the Stoner Pipeline Simulator (SPS) software[55]. The software has been developed and customized by Enbridge as the material balance system (MBS). The MBS system being used in 2010 was first installed in 1996. The MBS system was upgraded in about 2003 according to Enbridge MBS engineer[56]. Line 6B is divided into two separate volume balance sections for leak detection purposes.
See Attachment [22 & 24]

When an MBS alarm is received at a control center console it is reported to the MBS analyst for review. The MBS analyst uses multiple screens at least as shown in the simulated screens (see figures 6, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, & 22) to determine the location of the imbalance and to know whether the hydraulic model is working properly. If the model appears to be working properly and the parameters within the model look correct then the alarm condition is determined to be valid. Since the model is

[55] Stoner Model: This is the vendor that Enbridge uses their leak detection model.
[56] Interviews of Enbridge MBS Engineer on July 30, 2010

based on the crude oil being in a liquid state, the alarms are considered to be invalid when a condition known a column separation[57] appears on the pipeline. Column separation as stated earlier is a condition typically associated with large changes in elevation but will occur anytime the line pressure drops below the vapor pressure of the crude oil. When the vapor pressure drops below that of the crude oil, the pipeline is filled with a mix of both liquid and vapor which can render the hydraulic model unreliable. The use of the material balance system is to detect the presence of system leaks. While the operators have access to the same material balance screens that the MBS analysts do, as stated earlier they are not adequately trained to perform analysis, but it is the responsibility of the MBS analyst. According to interview statements from several operators they are not comfortable using the MBS screens and discerning the information provided. Analysis of the material balance alarms is left to the MBS analyst.

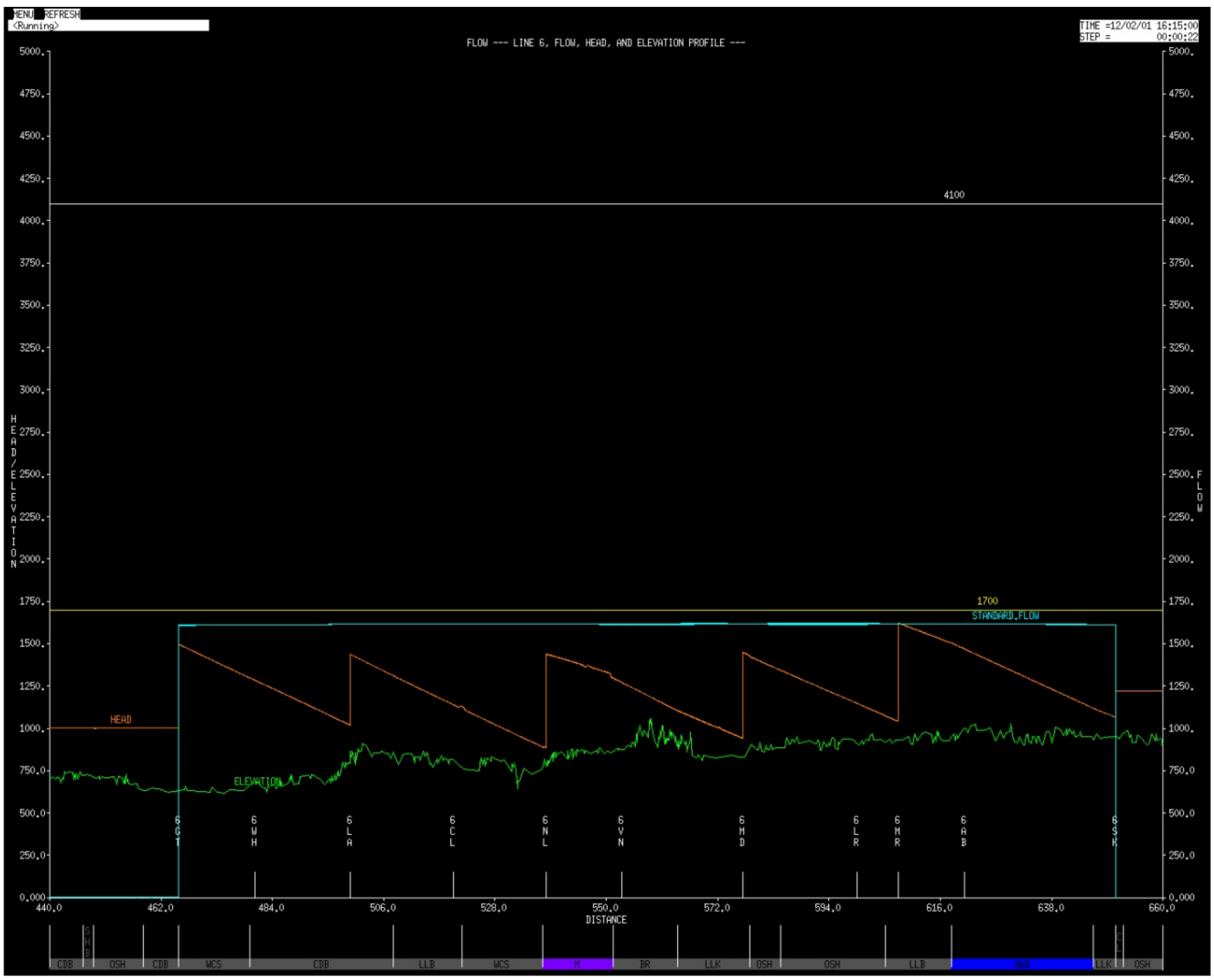

Figure 14: MBS Line 6 Flow Display Simulated – NTSB/PHMSA IR 358, Source: Enbridge No. 170255

[57] See Figure 16

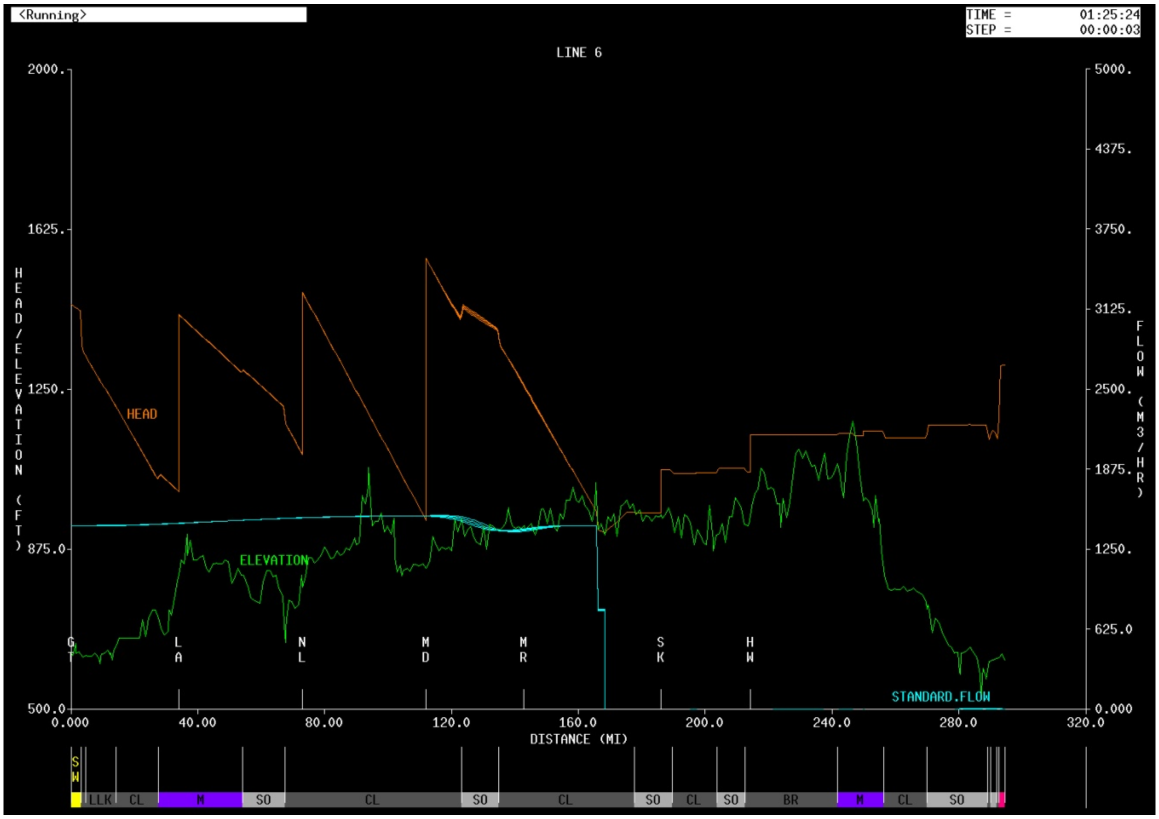

Figure 15: Line 6B Offline Simulated Leak – NTSB/PHMSA IR 358, Source: Enbridge No. 1622536

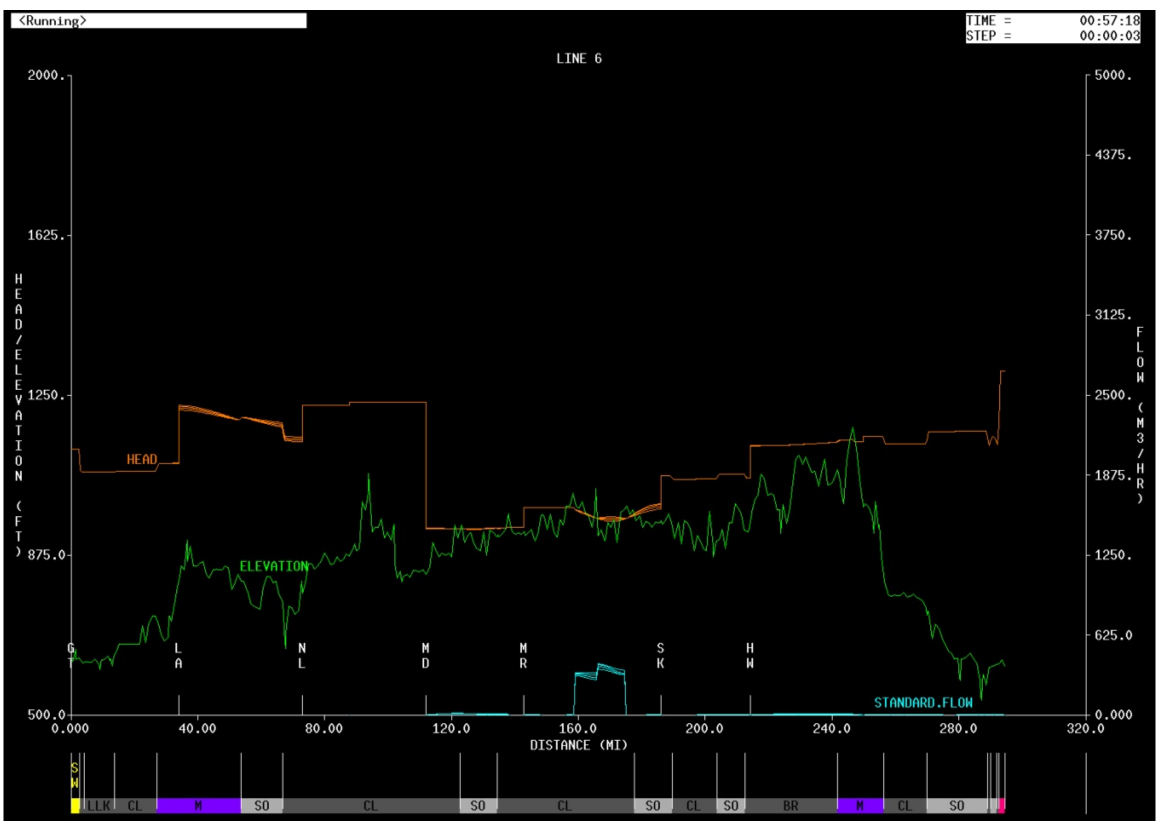

Figure 16: Line 6B Offline Simulated Column Separation - NTSB/PHMSA IR 358, Source: Enbridge N0. 152231

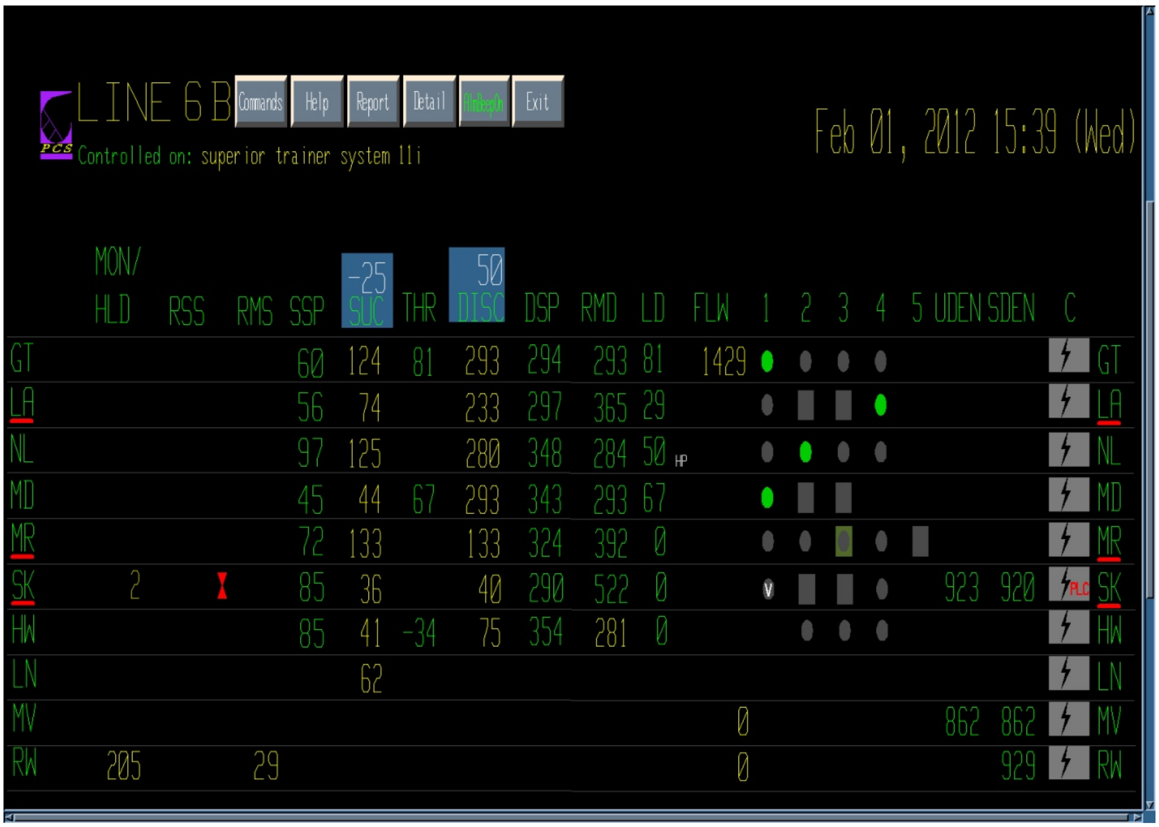

Figure 17: Line 6B Display Simulated Leak – NTSB/PHMSA IR 358, Source: Enbridge No. 162530

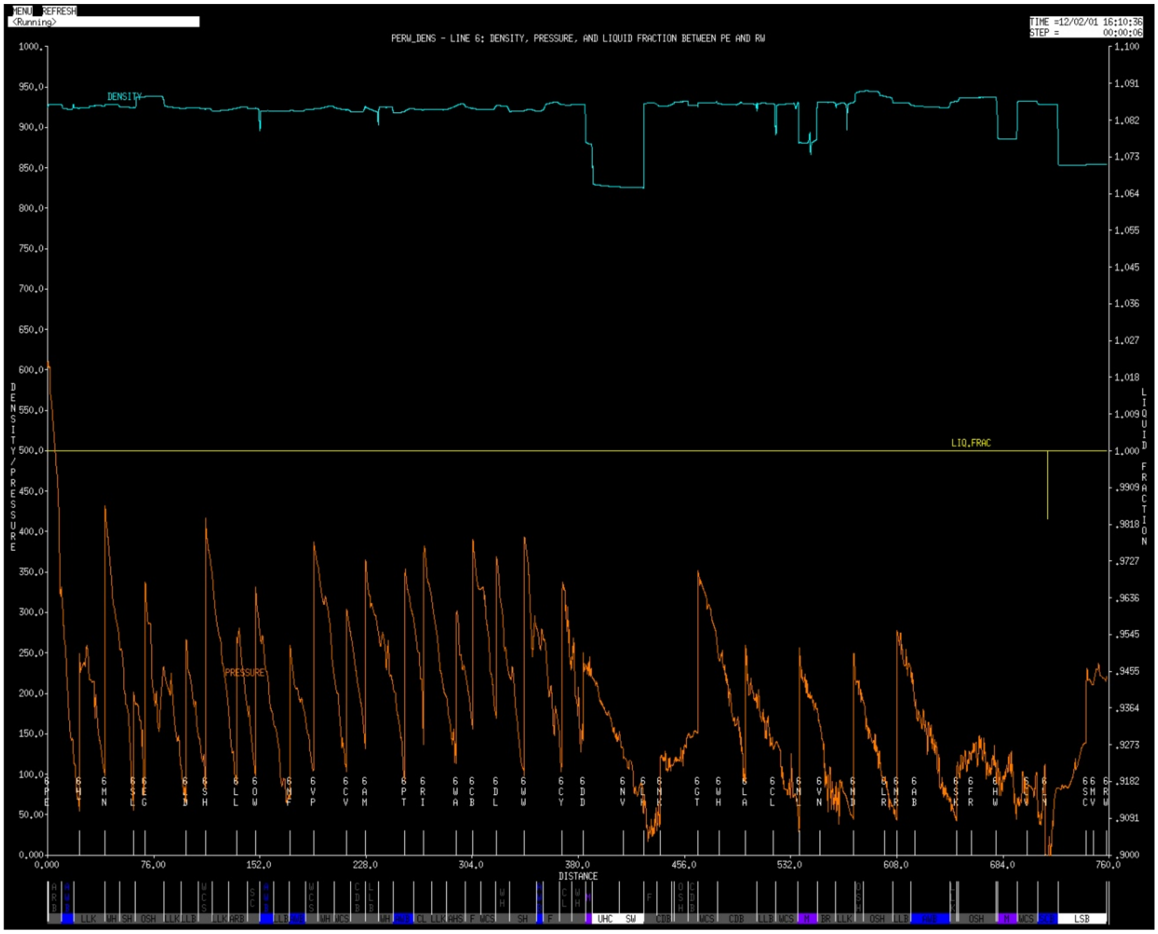

Figure 18: MBS Line 6 Density, Pressure and Liquid Fraction Simulated - NTSB/PHMSA IR 358, Source: Enbridge N0.165839

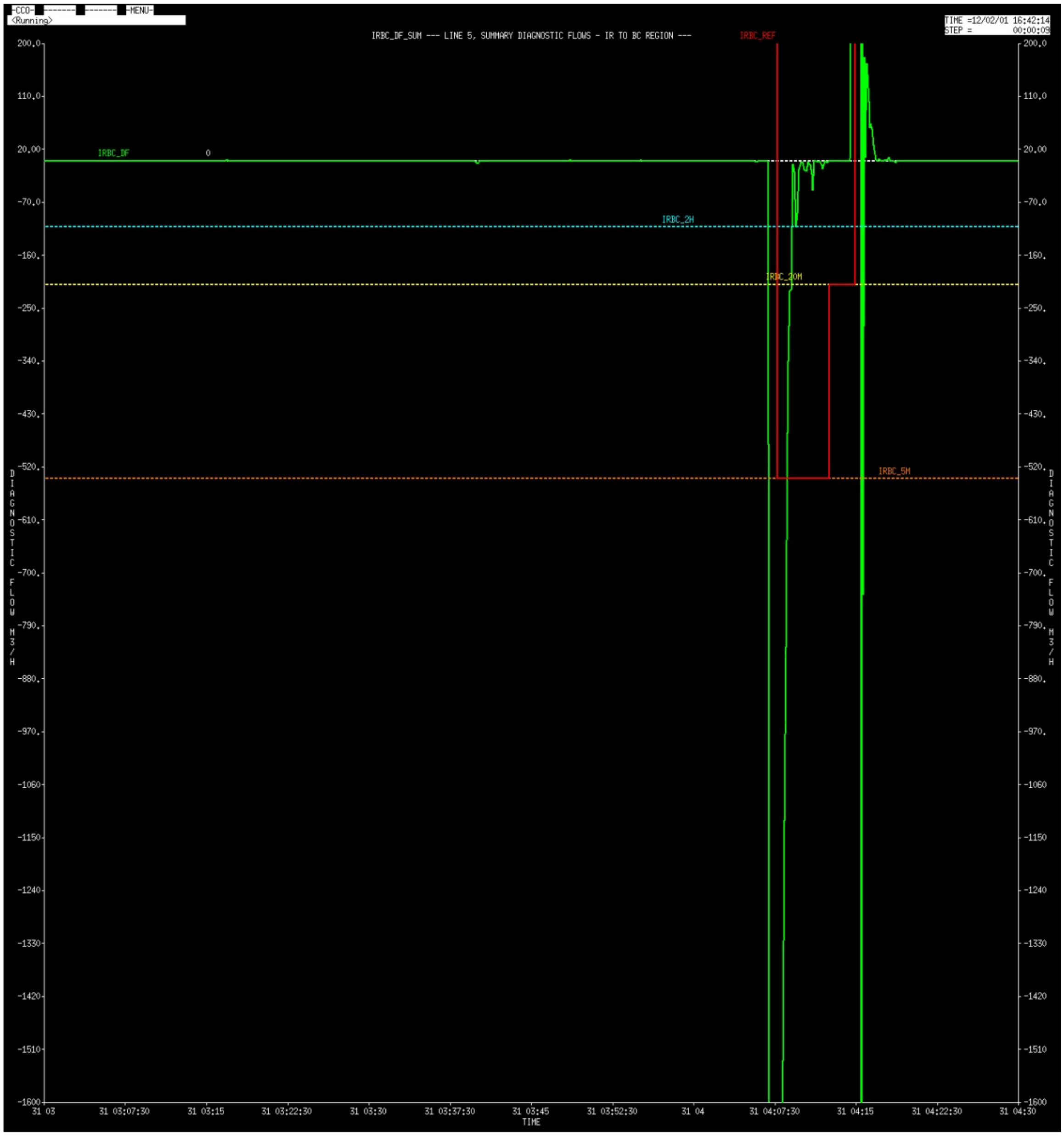

Figure 19: MBS Diagnostic Flow Summary – - NTSB/PHMSA IR 358, Source: Enbridge N0.172945

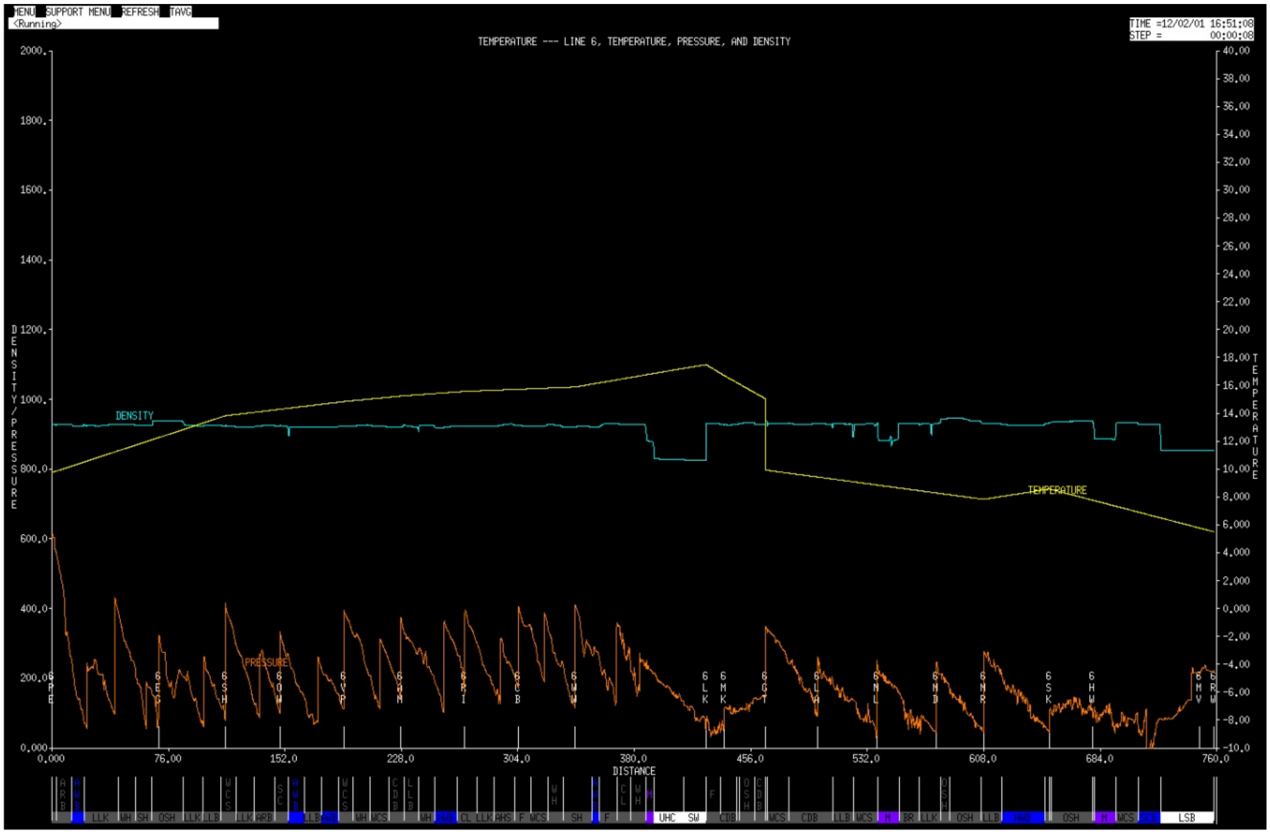

Figure 20: Line 6B MBS Temperature, Pressure, and Density - NTSB/PHMSA IR 358, Source: Enbridge N0.173935

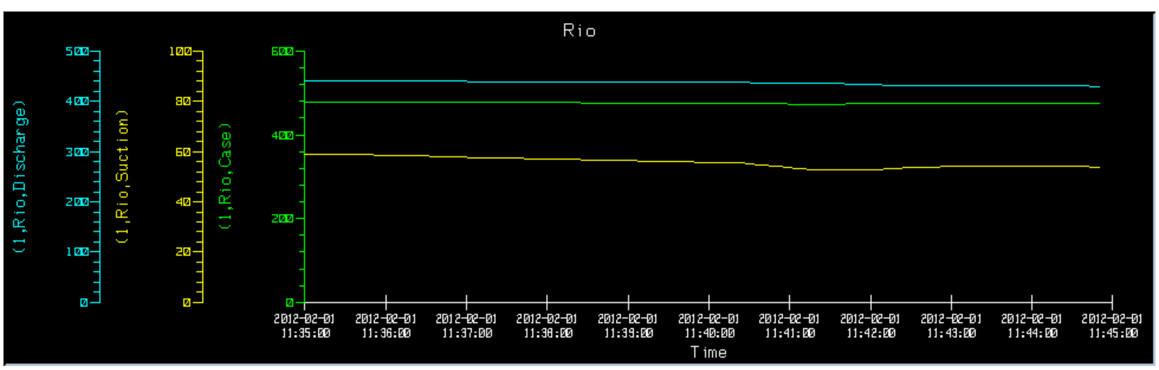

Figure 21: Rio - SCADA Trend Simulated - - NTSB/PHMSA IR 358, Source: Enbridge N0.123119

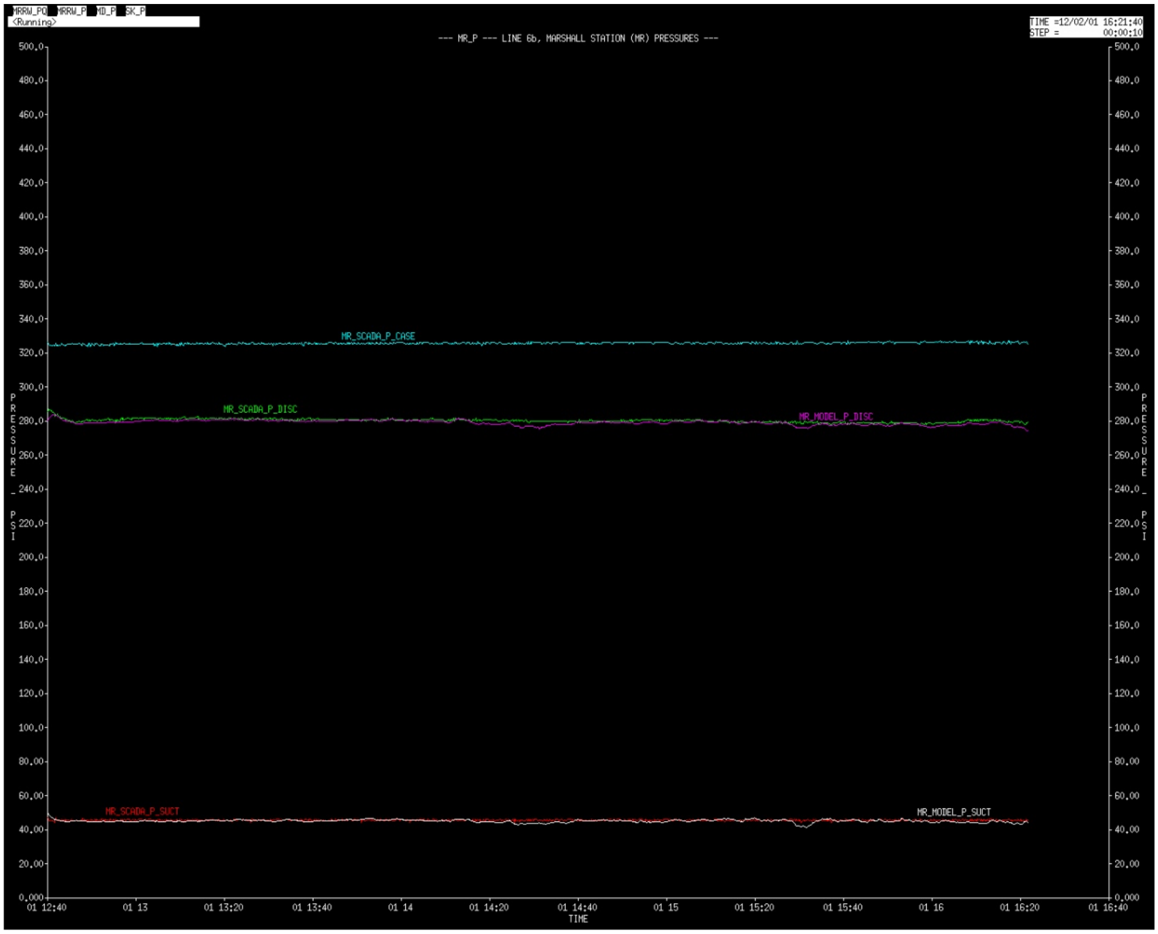

Figure 22: MBS Marshall Pressures -- NTSB/PHMSA IR 358, Source: Enbridge N0.170950

The MBS Leak Alarm – Analysis by MBS Support procedure required that if after 10-minutes[58], the analysis of the alarm is not completed or the alarm is valid then the pipeline is shutdown[59]. At the time of the analysis during shift A on July 25, 2010 Line 6B was already being shut-in.

Reviewing the cause behind an MBS alarm on this above date MBS Analyst A stated that he followed an MBS alarm flowchart to determine the cause of the MBS alarm. But MBS support response flow chart[60] required the MBS analyst to examine the diagnostic flows and all flow and all pressure trends before determining a column separation. If a liquid fraction was present, then the MBS analyst was to contact the shift lead and tell them that the model is showing column separation but that it was not reliable. The flowchart states that the MBS analyst was to tell the shift lead that it is the control center operator's decision to start the line. However, MBS Analyst B stated that it was the operator's job to examine the pressures.

[58] Referred to as the 10-minute rule in the Enbridge Control Center
[59] See Attachment 35: MBS Leak Alarm –Analysis by MBS Support procedure
[60] See Attachment 36: MBS Support Response Flow Chart

These pressure trends and diagnostic flows according to the MBS response flow chat contained enough leak triggers to confirm the leak at the time of the rupture if followed.

On July 26, 2010 at approximately 5:00 a.m. Shift Lead B1 reached the Control Center Operation Supervisor to let him know the problems the operating personnel were having on Line 6B. MBS Analyst B, Shift Lead B1&B2 who supposedly had reviewed the abnormal situations that were occurring on the line after 4:00 a.m. start up and shut down, had diagnostic control center screens available to them during the investigations. But though they reviewed the trends and historical SCADA data they did not notice the low pressures at Marshall.

According to Enbridge the MBS Analyst B had the opportunity of seeing the 5-minutes, 20-minutes, and 2-hours MBS alarms screens displays (figure 11, 12 & 13) showing how long the imbalances on the line had remained, and the volume of crude lost that could not be accounted for after pumping much oil into the line and received less or nothing at the destination locations. At the time Shift Lead B1 & B2 with MBS Analyst B performed their analyses and calculations, MBS Analyst B had seen the modeled liquid fraction (figure 18,)[61], the hydraulic profile with indications of column separation (figure 16), low density flow rate had remained as indicated where it existed, and the diagnostic flow summary which indicated how long the MBS alarms had remained (figure18 & 19).

MBS Analyst B similarly had a display (figure 22) used to review Marshall Pressures that had remained dominantly at zero psig, at the same time had display (figure 20) showing Line 6B MBS Temperature, Pressure, and Density used to review the pipeline conditions. These and associated displays both in SCADA and MBS led MBS Analyst B and Shift Lead B1 to state to the Control Center Operation Supervisor that these numbers does not look right, but attributed the problems to overcoming changes in elevation profile over a significant length of pipeline which led to column separation, power and unit outages, and Niles Station bypass leading to lack of enough upstream pressure before Marshall station[62]. Enbridge had consequently stated that column separation was not typical at Marshall, but at times when Line 6B is shut down, column separations have occurred downstream of Stockbridge between Howell and Sarnia[63].

During first start and second Line 6B restart at approximately 7:10 a.m. control center personnel had (figure 17) Line 6B display containing pipeline operation data from the previous day at shutdown. There were leak triggers available in the (see figure 10) historical SCADA data showing:

- cascaded pump self (PLC) shutdown at Marshall Station and
- zero suction and discharge pressures on shutdown at Marshall Station
- pipeline was shutdown with sufficient pressure to maintain minimum holding pressure in the pipeline segment

[61] Liquid Fraction: This is internally calculated model display in the MBS on a distance plot in real time.
[62] See Enbridge Control Center Transcripts
[63] NTSB/PHMSA IR N0 40

The control center personnel on this shift in their interviews stated they did not see the leak triggers. MBS Analyst B, Shift Lead B1 & B2 failed to extend their analysis to events preceding the time of the first pipeline startup attempt, according to Shift Lead B2 in an interview.

Following a recent interviews of Enbridge personnel with a Senior Technical Adviser Control Center Operation, Team Lead Leak Detection Assessment & Support, and Supervisor Training & Compliance Control Center Operation, who performed simulated demonstrations of Line 6B with the occurrence of column separation, and leak, which replicated the characteristics of the pipeline similar to the time of the incidents as shown in (figures 11, 12, 13, 14, 15,16,18,19,20,21, & 22) above, they think based on the simulations that the control center personnel had enough information and leak triggers to identify the leak at Marshall, Michigan. But the locations in these simulated displays were predetermined for this purpose.
See Attachment [10]

According to Enbridge suspect leak pipeline commodity movement tracking (CMT) Volume Difference Procedure; which states that *in the event of a leak trigger from the Commodity Movement Tracking (CMT) line-fill report,* the operating personnel are to*: verify that the volumes at both the pumping and receiving stations are correct, and if the volumes are correct and exceed the Volume Balance Threshold for the pipeline,* then operating personnel are expected to*; initiate a 10 minutes volume check at both the pumping and receiving stations; analyze PCS historical data, verify that negative volume imbalance was accompanied by a corresponding increase in pipeline pressures.* This procedure also requires the operating personnel to; *compare the volumes from the 10 minute volume check, and if the difference between the pumped volume and the landed volume from the 10 minutes volume check is more than 10%, or if the negative volume imbalance was not accompanied by a corresponding increase in pipeline pressure,* then *execute the Confirmed Leak – Pipeline – SCADA or CMT Data procedure.*

During Shift Lead B1 and MBS Analyst B discussions with Control Center Operation Supervisor**,** Shift Lead B1 mentioned that they started up Line 6B and it was drained off and quite often they have column separation at Marshall and typically have to fill it. That they started Line 6B and did not get pressure at Marshall Area for some time but got up to 4 pounds and the pressure did not increase. So they pumped in more into the pipeline expecting pressure but got nothing. They calculated their numbers looking at draining 632 cubic meters roughly. And once they figured they were not getting pressure, and since they got the numbers calculated they decided that 600 cubic meter should fill it. And they had shutdown, had put in 600 cubic meters but they took out 270 cubic meter which does not seem right. The operators and the MBS Analyst B calculated the pressure, they could not have put in 1,600 cubic meters to pack the line and nothing came out.

The the operating personnel saw pressures of only 4 psig maximum at Marshall during the two starts up and shut down which lasted for over five and half hours, but did not execute the suspect and confirmed leak – pipeline SCADA or CMT Data procedure[64] because they did not considered leak triggers such as:

- zero or low pressure at Marshall Station
- negative volume imbalance which was accompanied by decrease in pressure
- Multiple consecutives MBS alarms received (active)

There was no related FACMAN created by shift B operating personnel throughout their work period as resulting from abnormal operating conditions except for; Line 6B mile post 465.38 densitometer that was not working and a stated suspected rate loss which was said made it unable to start Line 6B due to problems at Marshall on July 26, 2010.

At start of shift C at approximately 8:00 a.m. on July 26, 2010 Operator C1, Shift Lead C1, & C2 according to their statements in the Enbridge control center transcripts and interview transcripts were briefed verbally during shift changeover with shift B operating personnel about the first and second Line 6B startup and shutdowns, multiple MBS alarms received, bypass at Niles station, column separation, pump unit power outages at La Porte, and the difficulties for not being able to fill up Line 6B.

Shift C operating personnel, Operator C1 said that what he was briefed during shift changeover did not make sense, and then reviewed Line 6B historical SCADA data back to the shutdown from the previous day because he was prompted by the amount of crude oil drained and to know how the pipeline was shutdown. During this historical data review, Operator C1 saw a significant pressure reduction at line shutdown, and then told and showed it to Shift Lead C1 who agreed with the finding. Operator C1 said it was a leak trigger because it happened at the time Line 6B was shutdown. Operator C1 went back to his console waited for directives on what next thing to do. Shift Lead C1 later went over to Operator C1's console and told him the leak had been confirmed and should go ahead to isolate the line[65]. Operator C1 told Shift Lead C2 that he thought the line pumps were sent stop commands to shutdown at the same time by Operator A1.
See Attachment [25] and [30][66]

Prior to receiving an emergency calls at approximately 11:17 a.m. about the crude oil pipeline leak at Marshall, Shift Lead C2 reached Electrician B at Marshall told him the difficulties the control center have had starting Line 6B and requested that Marshall Station be checked out for leak, but Electrician B stated haven taken a look throughout the station and everything was okay and found no leak. However, Electrician B mentioned that he saw the pressure at the station earlier at 4 psig and later it went to zero, but was told that because control center tried to start the line and it went to zero after shutdown.

[64] See Attachment: 25; Suspect Leak-Pipeline-From Commodity Movement Tracking (CMT) Volume Difference Procedure
[65] Attachment : 28 - Interviews of Operator C1
[66] Attachment: 30 – Suspected Leak – Pipeline –From SCADA Data

Shift Lead C2 reached the Regional Manager told him the problems they were having on Line 6B, and the column separations at Marshall and not being able to put it together, how they have started and shut down two times already but couldn't fill the pipeline. He described to him about the entire scheduled shut down the previous day while going to Stockbridge, startups, and shutdowns on July 26, 2010, while going to Sarnia, which they only got up to 4 psig and after calculations they found out that over 600 cubic meter had drained off during the shutdown. Shift Lead C2 stated they reviewed the pressures at the shut down the previous day, and noticed that the pressures right when the pumps were shut down, the pressures on the suction and discharge went to zero at Marshall, and whenever pressures at suction and discharge goes to zero you take a look around the station because something must be wrong. Whenever the suction and discharge goes to zero you will be checking for a leak, it means something happened at the station, and if all three transmitters went to zero at the same time. The control center continued with further investigations after talking to the Regional Manager.

The Enbridge control center Shift Lead C1 at approximately 11:17 a.m. over 17-hours after the rupture received a call on the emergency line from a consumer energy gas utility employee reporting of oil on the ground downstream of Marshall Station. Shift Lead C2 about 11:20 a.m. called the Chicago Regional Manager and told him they received a call from a Consumer Energy employee who said they had received calls from around two miles South of Marshall, near Highway 27 and Division Drive and that he had discovered oil on the ground.

Again Shift Lead C2 called Regional Manager told him he received a call from Enbridge field crew that there was oil on ground about quarter to half a mile downstream of Marshall Station. The Regional Manager then said he will be the Incident Commander for July 26, 2010, and some other person shall take over the next day, and then agreed that the Shift Lead C2 and the control center personnel should call the police and follow the Enbridge emergency response procedures.

H. Pipeline and Hazardous Material Safety Administration (PHMSA)

H.1. Computational Pipeline Monitoring (CPM) for Liquids

The U.S. code of federal regulation under 49 CFR part 195.444 refers operators of hazardous liquid pipeline transporting liquid in single phase (without gas in the liquid) to comply with American Petroleum Institute (API) recommended practice – API 1130 in operating, maintaining, testing, record keeping, and dispatcher training of the system.

However, scope limitations of this recommended practice may not apply to determining leaks during shut-in conditions that occur when the line is shutdown (sometime it is called static conditions). For instance, it states that; a Volume Balance CPM cannot evaluate volume loss if there is no flow through the meters during a line shutdown.

API 1130 also states that no one particular computational pipeline monitoring methodology or technology may be applicable to all pipelines because each pipeline system is unique in design and operation. Due to this uniqueness detectable limits are said to be difficult to quantify as a result of these characteristics on of each pipeline. Therefore, AP1130 recommends that limits must be determined and validated on system-by-system and perhaps a segment-by-segment basis.

H.2. Control Room Management

At the time of this accident on July 25, 2010 the control room management, U.S. code of federal regulation (CFR) under 49 CFR part 195.446 was published and operators had until August 1, 2011 to come into compliance integrating the section to the operator's procedures required by 49 CFR parts 195.402. In addition the training procedures required by paragraph (h) must be implemented no later than August 1, 2012.

H.3 Qualification Program

49 CFR part 195.505 (b & c). This part states that:

(b) Ensure through evaluation that the individuals performing covered task are qualified.
(c) Allow individuals that are not qualified pursuant to this subpart to perform a covered task if directed and observed by an individual that is qualified.

This part above consistent with Enbridge Energy procedures places Line 6B operating responsibilities on Operator A2 (mentor) during shift A, but she was pre-occupied working on assigned special project while Operator A1 (mentee) operated the lines which comprised lines 6A, 6B, 3, and 17 under his console.

I. Enbridge Post Accident Actions

Enbridge Energy currently states that they have multiple proposals for changes underway for their system which shall cover the following areas as related to this control room and SCADA operations report:

Pipeline Control Systems and Leak Detection (PCSLD)

1. Organizational Structure Changes
2. Process and Procedure Changes
3. Training Changes – Leak Detection Analyst
4. Instrumentation Changes
5. MBS Changes
6. SCADA/Pipeline Control System Changes

Pipeline Control Systems – Control Center Operations

1. Organizational Structure Changes
2. Key Procedures & Process Enhancements

3. Control Room Management
4. Training Development and Enhancements

See Attachment [40]

Attachments

Attachment 1: Figure 1 – Control Center Layout on 2010
Attachment 2: Interviews of Enbridge Operator A1 on July 28, 2010
Attachment 3: Interview of Enbridge Operator A2 on July 28, 2010
Attachment 4: Enbridge Control Center Transcript
Attachment 5: Enbridge SCADA Data Log Report from July 25 -27, 2010
Attachment 6: Interviews of Enbridge Operator B1 on July 29, 2010
Attachment 7: Interviews of Enbridge Operator B3 on November 2011 – Human Factors Interviews.
Attachment 8: Interviews of Enbridge Shift Lead A2 on December 15, 2010
Attachment 9: Interviews of Enbridge Shift Lead B2 on July 29, 2010
Attachment 10: Enbridge Control Center Recorded Simulated Demo, Source: NTSB, February 1, 2012.
Attachment 11: Suspected Column Separation –NTSB/PHMSA IR 183, Source: Enbridge Energy.
Attachment 12: IR 63 SCADA Control Center Emergency Procedures -Abnormal Operating Condition Requirements IR 63 –NTSBS-PHMSA, Source: Enbridge Energy
Attachment 13: Summary of MBS and column separation alarms at Marshall – NTSB/PHMSA IR 39
Attachment 14: Approved Suspected Column Separation Procedure – NTSB/PHMSA IR 178
Attachment 15: Unapproved Suspected Column Separation Procedures - NTSB/PHMSA IR 178
Attachment 16: Human Factor interviews of Operator B1, Shift Lead B1 and B2 on January 31, 2012
Attachment 17: Emergency Notification Procedures – NTSB/PHMSA IR 63 (see IR 6.1)
Attachment 18: MBS Leak Alarm –Temporary Alarms – NTSB/PHMSA IR 63 (see IR 6.1)
Attachment: 19 MBS Leak Alarm – Valid Alarm – NTSB/PHMSA IR 63 (see IR 6.3)
Attachment 20: Elevation Changes – NTSB/PHMSA IR 129
Attachment 21: MBS Systems -1; NTSB/PHMSA IR 1
Attachment 22: Interviews of Enbridge MBS Engineer on July 30, 2012
Attachment 23: Human Factor Interviews of Operator B2 on January 31, 2012
Attachment 24: MBS Alarms and Column Separation – NTSB/PHMSA IR 35 (IR 35.12)
Attachment 25: Suspect Leak – Pipeline – From Commodity Movement Tracking (CMT) Volume Difference Procedure
Attachment 26: Marshall Column Separation Rate –NTSB/PHMSA IR 40
Attachment 27: Electrician B Interview Transcripts on July 29, 2010.
Attachment 28: Interviews of Operator C1 on July 29, 2010
Attachment 29: Marshall Station PLC Pump Shut down
Attachment 30: Suspected Leak - Pipeline – From SCADA Data
Attachment 31: Interviews of Shift Lead B1 on July 29, 2010
Attachment 32: Source of 10-minute rules
Attachment 33: FACMAN Generations on July 25 & 26, 2010
Attachment 34: Line 6B Volume Balance Sections
Attachment 35: MBS Leak Alarm –Analysis by MBS Support procedure

Appendixes