National Aeronautics and Space Administration

SYSTEM FAILURE CASE STUDIES

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Under Pressure

On March 4, 1998, the Sonat Exploration Company in Pitkin, LA, began purging an oil pipeline to prepare for a new oil well. The well contained a high-pressure mixture of crude oil, natural gas, and water that would be separated in a newly constructed separation "train." Before beginning production, Sonat had to purge the pipeline to remove any air and gas already inside the pipes. The first stage of the purging operation was completed without incident. However, during the second stage of the purging process, one of the separation vessels became over-pressurized and ruptured, releasing flammable gas that subsequently ignited in a massive explosion. Four of the six workers on-site were killed immediately, and the incident caused $200,000 of facility and equipment damage (Figure 1).

Figure 1: The exploded vessel (no longer present) was to the left of the damaged storage tanks and identical to its older counterpart on the right.

BACKGROUND

Sonat Exploration Company's petroleum separation facility in Pitkin, Louisiana, was designed to process well fluids from several gas and oil wells in the Austin Chalk formation. The high-pressure fluids from the wells contained a mixture of crude oil, natural gas, and water. This mixture was to be directed via pipeline through a series of separation vessels that were all controlled by manual valves. This assembly, also called a separation "train," removed the natural gas and water in three progressive stages, sequestering the crude oil (and the natural gas) for sales.

Figure 2 displays a schematic of a separation train like the one used in Pitkin, LA, where the constituents of the well fluids were to be separated over three stages. The first stage separator vessel was designed to handle the highest pressure coming directly from the well. The maximum safe operating pressure was 1440 psig, where psig is the differential between internal pressure and atmosphere. With some of the natural gas and water removed from the crude oil, the pipeline would pass a lower pressure mixture of fluids to the second stage separator vessel, which had a maximum safe operating pressure of 500 psig. More of the natural gas and all of the water was to be removed before the fluids reached the third stage separator, which could only operate safely at atmospheric pressure (0 psig). Typical operating pressures were well below maximum allowable pressures for the first and second stages at 900 and 225 psig, respectively. The third stage, however, was designed to operate exactly at atmospheric pressure.

An over-pressurized vessel ruptured and then exploded, killing four workers.

Proximate Cause:

- Two valves were incorrectly set to the closed position, blocking the pressure relief system in the bypass line

Underlying Issues:

- The lack of a formal design review process allowed key design deficiencies to go unnoticed
- There were no written or documented procedures, checklists, diagrams, or instructions for operations
- Operators were not provided with site-specific or process-specific training

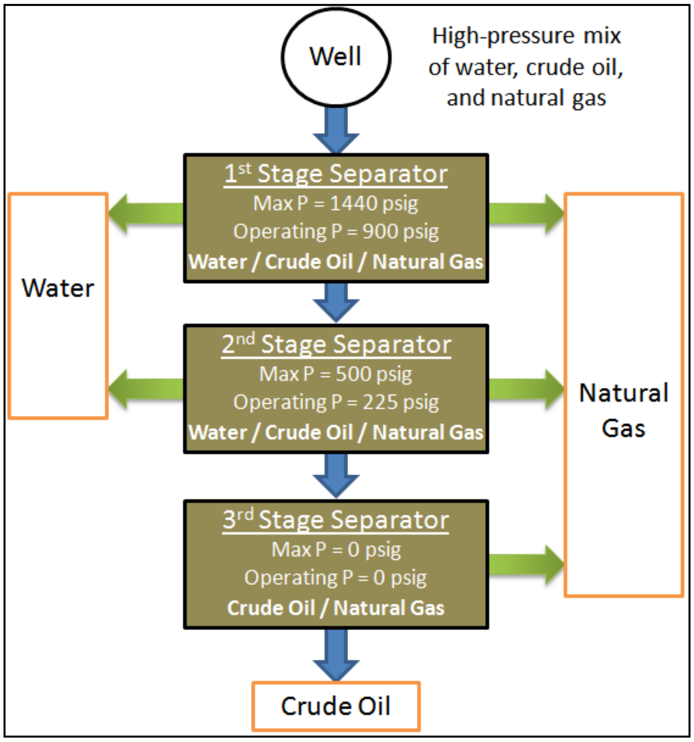

Figure 2: A separation train uses three separator vessels to progressively sequester components for storage and sales.

What Happened?

Purging the Pipeline

At the Pitkin facility, Sonat was scheduled to begin production from a new well on March 4, 1998, using a newly constructed separation train. Before production could begin on the new train, the pipeline had to be purged to remove any air or gases residing inside. During purging, the separation vessels were to be closed off by arranging the valves to direct the well fluids through the "bypass lines," as shown on the left side of Figure 3. The first and second stage separators could be isolated by closing the valves controlling the inlet and outlet of the vessel and by opening the valve in the bypass line. The third stage separator, however, did not have a valve to close the inlet. Instead, there was a pneumatic valve in the bypass line (that would open automatically in response to high fluid pressure) surrounded by valves that could be manually opened or closed.

Both the pipeline from the new well and the new separation train had to be purged before Sonat could start production. The first phase connected the new separation train to an older well to test out purging on the new equipment. After validation of the new separation train, the valves would be reconfigured to connect to the new well (located two miles away) for a second purging phase. This second phase was meant to purge the two miles of pipeline specifically connecting the new well to the separation train. During both of these operations, the storage tanks (for the natural gas, crude oil, and water) would be left open so that air and gas could be released as the pipeline was being purged.

The first phase of purging occurred as planned without incident. The crew then began preparations to purge the pipeline from the new well. To execute this switch, 11 valves had to be manually repositioned—without the benefit of checklists or written procedures. It was critical that the two valves around the pneumatic valve be opened to allow flow from the new well to pass through the bypass line. Both of these valves were open during the first purge, but at some unknown time during or after the realignment, they were both incorrectly moved to the closed position, meaning that there was no pathway for fluids or gases to escape the third stage separator vessel.

There were a total of six employees on-site at this time. One contracted operator was located at the old separation train, while the construction supervisor, three contracted operators, and one Sonat operator were all stationed at various key places along the new separation train. The Sonat production supervisor was not present but was en route to the facility.

For reasons unknown to the survivors, at about 6:00 pm, four of the operators left their respective stations and went to the third stage separator vessel. The construction supervisor was checking on a pipeline valve about 300 feet away, while the one remaining contract operator stated that he heard one of the four operators mention going to "check the tanks." It is unknown whether the vessel produced any indication of the over-pressurization that was occurring, since it did not have a pressure sensor or alarm. At 6:15 pm, approximately one hour into the second phase of purging, the vessel burst. Flammable gases immediately ignited into a large fireball (from an undetermined ignition source). All four operators near the vessel were killed instantly, while fires fueled by natural gas leaking from the tanks destroyed equipment and nearby cars.

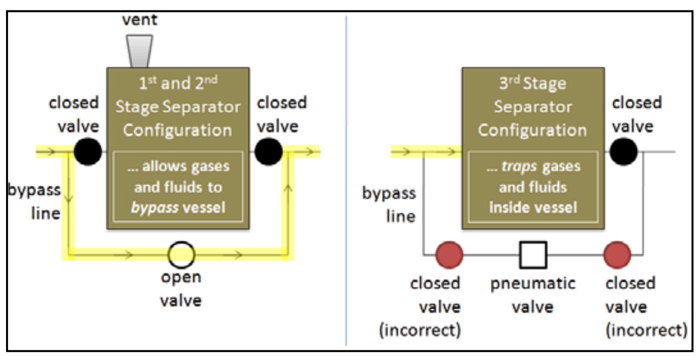

Figure 3: Key design differences between the 1st and 2nd separator vessels (left) and the 3rd separator vessel (right). The path of fluids and gases are highlighted.

Proximate Cause

Two critical valves in the bypass line were incorrectly in the closed position (see Figure 3), preventing the purged gases from venting into the atmosphere as necessary. Instead, the well fluids and pipeline gases were forced into the third stage separator vessel, where they were trapped. Different investigation groups, including the Chemical Safety Board (CSB), the Oak Ridge National Laboratory, and Sonat itself, estimated that the pressure inside the vessel that was designed to operate at atmospheric pressure had risen to anywhere between 135 to 400 psig before bursting.

Underlying Issues

Lack of Formal Design Review

The design and construction of the facility, pipeline, tanks, and valves did not undergo formal design reviews, nor was the design properly documented in any sort of process or instrumentation diagram. Figure 3 displays the configurations for the three separator vessels, showing the key design differences between the first two and the third. First, the third stage separator vessel was the only one of the three designed to function at its maximum allowable pressure for safe operation, leaving very little margin for error. Second, it did not contain a valve to close off the inlet to the vessel. Therefore, even when operated properly, the vessel could not be blocked from the unwanted entry of fluids or gases. And finally, the vessel was not equipped with an atmospheric vent to protect against over-pressurization. The CSB investigation stated that a formal design review and hazard analysis process would have likely identified the design shortcomings for an over-pressurization scenario and that the absence of accurate engineering drawings for process and instrumentation was a severe impediment to an effective review process.

The American National Standards Institute (ANSI) and American Petroleum Institute (API) maintain recommended practice guidelines for separator vessels, specifying the need for pressure-relief systems on all oil and gas separators. Sonat even had its own standards acknowledging these recommended practices; however, Sonat had classified the third stage separator vessel as a "storage tank" that was exempt from the standards. The CSB concluded that this classification was incorrect and that the vessel was in fact a separator and should have been designed in compliance with the ANSI/API specifications. They also noted that even if the classification as a storage tank had been correct, ANSI/API specifications would still have called for the incorporation of pressure-relief systems. In their final report, the CSB stated that such a pressure relief system would likely have prevented this mishap.

Insufficient Operating Procedures

In addition to the design and review deficiencies, Sonat did not provide workers with written operating procedures regarding any specific oil and gas production activities. Operators relied solely on oral instructions, Sonat's preferred methodology for training and operations. The lack of written checklists, documented valve positions, or other operational setup diagrams thus required senior operators to know exactly what to do in each situation from memory and to guide less experienced operators by verbal direction. In the absence of written or documented procedures, the likelihood of error, omission, or oversight was substantially increased given the large number of critical valve operations that all had to be conducted manually. Another result was that there existed no records of when the faulty configurations may have occurred or who may have been responsible for the changed valve settings.

> "Neither design review nor hazard analysis can be conducted in the absence of accurate engineering drawings..."
>
> *-Chemical Safety Board Investigation Report*

Inadequate Employee Training

The training program at Sonat consisted primarily of on-the-job training, supplemented by monthly internal safety meetings and external coursework on subjects like Hazardous Waste Operations, Emergency Response, and Job Safety Analyses. However, none of these focused on specific processes or operations at any particular facility. Sonat did not provide a formal site-specific or process-specific training program. Even though Sonat workers routinely switched sites, they were never trained to handle any variation in design, processes, or operations at the various facilities.

The monthly safety meetings included reviews of recent incidents or near-misses and Job Safety Analyses, which was a procedure meant to uncover any new hazards or hazards that may have been previously overlooked. While attendance at these meetings was recorded, there was no actual evaluation program in place to ensure that the information provided was thorough, accurate, or consistent. There were no assurances that erroneous, unsafe, or incomplete operating procedures were not being propagated. And, there was no confirmation that the workers even understood the information that was communicated to them. The CSB added that contracted workers were likely to be even less trained than the Sonat operators.

Aftermath

The Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard contains requirements concerning process hazard analyses and the use of written operating procedures. Oil and gas production facilities were thought to be exempt from the OSHA PSM standard, but OSHA issued citations to Sonat for violations of the PSM requirements along with a letter stating that the standard did in fact apply to Sonat's facilities. The API objected to OSHA's new interpretation of the PSM standard, contending that such a substantive change required a rulemaking process and analysis of economic and technological feasibility. OSHA ultimately withdrew the citations but maintained that the PSM standard was intended to apply to oil and gas production facilities.

Recommendations issued by the CSB to Sonat included instituting a formal design review process for all oil and gas production facilities in Sonat's businesses. Additionally, CSB recommended implementing a program to ensure that equipment vulnerable to over-pressurization be equipped with adequate pressure relief systems and that compliance be audited. Further, it was recommended that Sonat develop written procedures for all the processes at oil and gas facilities, as well as provide formal training programs in applying these procedures. Finally, the CSB recommended that the API develop and issue guidelines specifically addressing safe start-up and operations of oil and gas production facilities.

Applicability to NASA

Formal design reviews and hazard analyses provide opportunities to identify design flaws and potential failure modes. The Sonat facility had a number of key design deficiencies which were not recognized until the mishap. Improper application of design requirements and specifications contributed to these deficiencies: although the ruptured vessel functioned as a separator, Sonat considered it a storage tank. This classification led to several critical design flaws in the facility. The CSB stated that a formal review would have identified these deficiencies and that proper hazard analyses would likely have predicted an over-pressurization scenario. Formal design reviews and hazard analyses are essential, along with careful assessment of the standards and requirements governing NASA programs and projects.

Effective design review and hazard analysis would have been almost impossible in this situation because Sonat did not produce engineering drawings of process equipment. A piping and instrumentation diagram (P&ID) shows all the piping, valves, reducers, equipment, instrumentation, and interlocks for a particular process system. P&IDs are a critical visual reference that must be used during maintenance or modification of the process system to determine sequences of operations and control.

In addition to lacking engineering drawings, the Sonat facility did not have documented processes or procedures. Written and approved operating procedures promote safe operations and ensure that operators have adequate information to accomplish tasks in the required sequence. Relying solely on oral communication puts projects at unnecessary risk. The CSB noted that Sonat's lack of documentation would have made proper design reviews or hazard analyses difficult. NASA must ensure that all designs, changes, procedures, and activities are properly documented to confirm accuracy, consistency, and record-keeping, even for routine tasks.

While on-the-job training is commonplace in many industries, NASA must be sure that the training for program and project personnel is sufficient for the particular mission at hand. This also applies to the contractors that NASA utilizes. Sonat operators did not receive site-specific or process-specific training. Management must evaluate the thoroughness and accuracy of its own training program, as well as assess its effectiveness for employees. The purpose of training is lost if the content is inaccurate, misunderstood, irrelevant to the tasks at hand, or simply not used. NASA must ensure that employees understand and utilize all applicable training resources.

Questions for Discussion

- Do you have a formal, documented design review and hazard analyses process?
- Are designs, instrumentation, and proper configurations diagrammed and/or officially documented?
- Are procedures written or documented to the extent that exact actions are retraceable?
- Do training programs evaluate your understanding or retention of information?
- Are operators (including contractors) provided the site-specific or process-specific training necessary to implement mission tasks?

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Executive Editor: Steve Lilley steve.k.lilley@nasa.gov
Developed by: ARES Corporation

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