Process Safeguards and Risk Analysis for Offshore Processing

S.H. Landes, H.H. West, and E.M. Stafford
Shawnee Engineers
3644 Westchase
Houston, Texas 77042
hhwest@pdq.net

and

M.S. Mannan
Mary Kay O'Connor Process Safety Center
Chemical Engineering Department
Texas A&M University
College Station, TX 77843-3122
mannan@tamu.edu

Presented at the ***2000 Annual Symposium***, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, Texas, October 24, 2000.

ABSTRACT

Process safeguards have been traditionally designed into petroleum processing systems. The confined and remote nature of offshore petroleum added special conditions to process safeguard requirements. Increased regulatory involvement in the offshore petroleum processing industry has formalized traditional industry practice. Most of the regulatory approaches follow either the U.S. model or the North Sea model, with minor variations.

With increased regulatory involvement, formal risk analysis has been added to the safety evaluation requirements of offshore production designs.

Introduction

The offshore petroleum industry started in the late 1950s with fixed production platforms in the Gulf of Mexico. The offshore petroleum processing is not extremely complex conceptually, typically including flow-lines, separation, and pumps & compressors. The size and quantity of the processing units varies from simple single well processing units to very large systems processing oil and gas from many wells. Platforms, which have the capability of drilling as well as petroleum production further, complicate the platform processes.

At the present time there are approximately 3,850 producing platforms in the offshore US Gulf of Mexico

In the Beginning

There are very little in basic design safety systems that were not functionally similar to the onshore oil and gas plants of 50 years ago. Modern electronic shutdown systems replace older pneumatic systems, but the basic functions are comparable. Automatic systems now replace manual control systems.

Codes & Standards

The American petroleum industry over time had created a number of recommended practices and specifications for equipment used in petroleum processing prior to the onset of the offshore industry. An example is API Specification 6FA, “Fire Test for Valves”, which is the latest addition to the defining of performance of valves when exposed to fire conditions. There are innumerable recommended practice documents and specifications for equipment components within the API entire processing system.

The API series 14, entitled “Offshore Safety and Anti-Pollution”, is a series of recommended practices listed in the Appendix. In the area of process safeguard design and analysis, the API recommended practice 14C “Analysis, Design, Installation, and Testing of Basic Surface Safety Systems on Offshore Production Platforms” was the first guideline for design of process safeguards.

US Gulf Of Mexico Regulations

The primary regulations covering the US Gulf of Mexico offshore area are 30 CFR 250 and 30 CFR 256. Design requirements are incorporated in 30 CFR 250 for offshore production platforms.

The Minerals Management Service (MMS) is a bureau within the U.S. Department of Interior. The MMS promulgates and enforces the regulations for the outer continental shelf (OCS), which the US federal government defines as the offshore water surrounding the U.S. The OCS is defined as the farthest of 200 nautical miles (1.1 statute miles) seaward from the baseline of the territory.

The MMS was created in 1982. Prior to that time, the U.S. Coast Guard had responsibility for safety of offshore operations. The MMS specifically requires compliance with API Recommended Practice 14C , mentioned previously herein, as a matter of regulation.

API RP 14C

API 14C, "Recommended Practice for Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms ", was developed in the early 1970s specifically for the offshore petroleum production facilities.

API 14C, like traditional chemical engineering unit operations, focuses on identification of the safety systems (also called process safeguards) which protect the process unit from failure. It also provides a method for safety analysis of the process unit within its interconnected process environment.

One of the most important objectives of API 14C is to provide the format for documentation of safety and protective systems on offshore production platforms. Furthermore, in accordance with prudent safety practice, the methodology of API 14C is premised on providing *two independent* levels of protection for each identified failure mode of every process unit.

Similar to portions of both the HAZOP and FMEA techniques, API 14C actually presents a process hazard analysis methodology for generically similar process equipment commonly used in petroleum production. The API 14C analysis does not attempt to quantify the potential consequences of the identified equipment failure modes.

API 14C recommends *safety critical* instrumentation and related safety protective systems to typical production processing units (such as pressure vessels, tanks, pumps, etc.). These recommendations are based upon the concept that containment of hydrocarbons is the primary goal of safety. Hence, these process unit recommendations are coupled to specific undesirable failure events, such as leak, overpressure, etc. API 14C also includes the recommendation that redundant (at least two independent systems) critical instrumentation or protective systems be installed for each failure mode of a hydrocarbon containing processing unit.

The API 14C concept provides a methodology to combine the safety protective systems of each individual processing unit into a rational linked total system. Furthermore, it provides a report format (the Safety Analysis Function Evaluation or SAFE chart) which is a powerful audit trail to document the safety systems for future reference.

Several misconceptions regarding API 14C persist among those unfamiliar with this methodology. API 14C focuses on detection of each identified failure mode. The designer is free to select the proper control response. Hence, automatic shutdown of a particular valve, or opening a controlled blowdown vent, or alarming a high pressure signal to the manned control room (for operator manual actions) are all appropriate and agreeable within the API 14C reporting format. Manual response systems are <u>not excluded</u> from compliance within API 14C.

Another common misconception is the extension of the redundant system recommendation to non-hydrocarbon portions of the processing units. For example, leak of cooling water systems is not regarded as a failure mode that would carry a redundant detection system.

A major advantage of the API 14C methodology is the highlighting of safety protective systems that are primarily provided for containment integrity purposes. Most of the new OSHA and MMS require additional testing, quality control, etc. for "critical" equipment. The instrumentation listed on the API 14C SAFE chart is the critical equipment, hence serves as the basis for compliance with other segments of the OSHA process safety regulations.

The Process Safety Flow diagram, which accompanies the SAFE chart, is a unique chronicle of the design decisions related to safety critical instrumentation. This specialized P&ID is not only limited to only safety critical instrumentation, but clearly indicates the instrumentation which is shared by connected process units. The SAFE chart and the Process Safety Flow diagram are particularly helpful documents during the periodic safety review, MOC review, or HAZOP procedures.

The API 14C process hazard analysis can be briefly summarized as follows;

Recommended safety devices are graphically illustrated, as in figure 1 (for the basic pressure vessel, figure A4 in API 14C) for each major process unit identified in the process flow diagram.

Figure 2 shows the corresponding safety analysis table (SAT) for pressure vessels (table A4.1 of the API standard), which is functionally similar to the FMEA format. This table presents a set of guidewords for each potential failure mode or undesired event, such as high pressure, fuel failure, etc. Notice that the SAT recommends protective devices for each process unit, in direct correspondence to each potential undesirable event.

The process engineer customizes and expands the SAT by completing a protective system specification table, such as the example shown in figure 3, while also using the corresponding API safety analysis checklist (SAC) for each type of process unit. A reduced print copy of the pressure vessel SAC is attached in the Appendix

From the completed specification table, the protective devices are over-layed onto the process flow diagram, illustrated in figure 4. The dotted circles indicate recommended sensors **not used** for the cited reasons.

Finally, the results of this analysis are compiled on the SAFE (Safety Analysis Function Evaluation) chart, shown in figure 5 and correspondingly noted on the modified process flow schematic, shown in figure 6.

Note that this modified process flow schematic is commonly called a process safety flow diagram. It is somewhat similar to a P&I diagram, but focus only on the safety protective systems and do not show operational controls. Hence, the process safety flow diagram is a special P&I diagram which was developed to highlight the safety protective systems.

Hence, the standard deliverable API 14C safety documentation consists of the following;

process flow diagrams

process safety flow diagrams
SAFE charts

The working documents needed to complete these deliverables include the generic SAT, SAC, and the safety protective devices specification data sheet.

The safety protective devices specification data sheet, as shown in figure 3, must be retained as a project document. Notice that this table provides the essential link between identified failure mode and both safety protective devices installed to prevent incident propagation to a catastrophic containment failure. This document is basically a customization of the API 14C SAT for the specific production unit.

Rather than using the basic generic SAT and graphic for a petroleum production pressure vessel (as shown in figure 1 and 2), it is much more efficient to develop a recommended standard for each of the many types of pressure vessels found in petroleum production systems, such as high pressure separators, low pressure separators, 3 phase separators, compressor knockout drums, etc.

The API 14C standard has developed recommendations for the following equipment types;

Wellheads
Flowlines & manifolds
Pressure vessels
Compressors
Pumps
Tanks
Process Buildings

Safety and Environmental Management Programs

The Mineral Management Service (MMS) developed the Safety and Environmental Management Plan in response to the 1990 finding of the National Research Council Marine Board that compliance mentality was not conducive to effectively identifying all potential operational risks when developing comprehensive accident mitigation plans. In response to the National Research Council findings, API, in cooperation with MMS, developed Recommended Practice 75, “Development of Safety and Environmental Management Programs for Outer Continental Shelf

Operation Facilities" (SEMP). s. Unlike many other MMS rulings, the SEMP program is voluntary. The API con-ducts annual SEMP implementation surveys.

API also produced a companion document, RP 14J, for identifying safety hazards on offshore production facilities. This recommended practice provide procedures and guidelines for planning and arranging offshore production facilities and performing hazard analysis on open-type offshore production facilities. It discusses procedures that can be used to perform hazard analysis and prevents minimum requirements that can be used for satisfying API RP 75

Basically, the minimum process safeguards for simple unmanned platforms is compliance with API 14C. More complex platforms require additional process hazards analysis as defined in API 14J.

Norwegian North Sea Regulations

The Norwegian Petroleum Directorate (NPD) controls the regulatory regime in the Norwegian sector of the North Sea. NPD favored goal-setting rather than prescriptive regulations and converted all previous regulations to this type in the 1985 – 1992 period.

Two principal elements of this regulatory regime are the systems of internal control and risk assessment. The "Guidelines for the Licensee's Internal Control, 1979" described a safety management system. The "Regulations Related to the Licensee's Internal Control, 1985" essentially made this a regulatory requirement.

The "Regulations Concerning Safety Related To Production And Installation, 1976", contained requirements for platforms which have living quarters. These regulations included a risk evaluation that was largely qualitative.

A more quantitative risk evaluation was proposed in "Guidelines for Safety Evaluation of Platforms, Conceptual Design, 1981". This was the beginning of the concept safety evaluation and quantitative risk assessment in the North Sea. The guidelines defined a design basis accidental event (similar to the concept first proposed for nuclear design basis accident evaluation). The foundation of these analyses included:

- At least one escape path shall be intact for at least one hour during this design basis accidental event.
- A shelter-in-place area shall be intact until safe evacuation is possible.
- Main platform support structure must maintain a float-carrying capability for a specific period of time.

The categories of events which were to evaluated were specified as:

- Blowouts
- Fire.
- Explosion.
- Ship and helicopter collision.
- Earthquake.
- Falling objects
- Extreme Weather

The guidelines gave explicit numerical criteria. It was considered necessary to exclude the most improbable accidental events from analysis. However, total probability of occurrence of each type of excluded situation should not, by best available estimate, exceed 10^{-4} per year for any of the main functions specified. This number is meant to indicate the magnitude of risks, for which a project must serve as a goal, including detailed calculations of probabilities, which in many cases were unavailable due to lack of relevant data. The use of risk assessment was increased in the "Regulations Relating to the Implementation and Use of Risk Assessment in Petroleum Activities, 1990". Basically this is a flexible system, trying to avoid degenerating into a "numbers game".

However, the OREIDA equipment failure database was born in response to this requirment for quantitative risk analysis.

UK North Sea Regulations

At the beginning of the development of the UK sector of the North Sea, the Department of Energy was the agency in control. Regulations in 1971 were complemented by guidance documents that had the effect of being part of the regulation. The guidance documents were very prescriptive in nature. The regulations made it difficult to take an integrated approach. For example, the passive and active fire protection methods were the subject of two separate sets of regulations. A proposed platform operator was required to obtain certification by "certifying authorities” acting on behalf of the Department of Energy. The certifying authority reviewed the process design and inspected construction to confirm compliance. Several different agencies were involved.

The Burgoyne Report in 1980 recommended placing all authority with the Department of Energy and enhancing their capabilities.

In the wake of the Piper Alpha accident, the basic framework in the new offshore safety regime is goal setting regulations rather than prescriptive regulations. The first set of these type regulations was formulated in the Offshore Installation (Safety Case) Regulations of 1992. The Cullen Report on the Piper Alpha accident made recommendation #1 that the offshore operator should submit a “Safety Case” to the regulator.

The UK CIMAH regulations of 1984 had a requirement for safety case analysis. Safety Case has a special meaning in connection with CIMAH regulations. The CIMAH regulations define the Safety Case as a hazard study, which is required for every plant falling within the scope of the regulations. The Offshore Safety Case is largely modeled on the Onshore Safety Case, but it has three additional features: safety management system, temporary safe refuge, and quantitative risk assessment (QRA).

Essentially, the QRA is the responsibility of the platform operator. The Safety Case involves a demonstration that the frequency of events, which threaten the endurance of a temporary safe refuge, will not exceed a certain value. In order to provide at least one fixed point in the regulatory regime, both minimum endurance capacity and frequency with which such insurance are specified by the HSE.

Conclusions

The process safeguards actually used by the offshore petroleum processing industry worldwide are functionally similar. The safety reports and regulatory paperwork, however, differ substantially due to varing government regulations.

Figure 2

Safety Analysis Table for Pressure Vessels

UNDESIRABLE EVENT	CAUSE	DETECTABLE CONDITION AT COMPONENT	RECOMMENDED SAFEGUARDS	
			Primary	Secondary
Over-pressure	Inflow Exceeds Outflow Thermal Expansion Blocked Outlet	High Pressure	PSH	PSV
Under-pressure	Withdrawals Exceed Inflow Thermal Contraction	Low Pressure	Gas Make-up System	PSL
Overflow	Liquid Inflow Exceeds Liquid Output Capacity Level Control Failure	High Liquid Level	LSH	*LSH and *PSH
Gas Blowby	Level Control Failure	Low Liquid Level	LSL	*PSH and *PSV or *Vents
Leak	Deterioration Rupture Accident	Low Pressure and Backflow	PSL and FSV	ESS
Excess Temperature (Process)	Excess Heat Input	High Temperature (Process)	TSH	Safety Devices on Heat Source

Figure 3 Process Safety Protective Devices - API 14C

Pressure Vessels

Failure Mode	Limit	SAFETY PROTECTIVE DEVICES Primary		Secondary	
		sensors	actuators	sensors	actuators
high pressure	_ psig	PSH ____ or SAC#____	_______	PSV _____ or SAC#_____	
low pressure	_ psig	FCV ___ or SAC#____	______	PSL _____ or SAC#_____	___
liquid overflow	__ ft	LSH ____ or SAC#_____	_____	PSH ____ or SAC#____	___
gas blowby	__ ft	LSL _____ or SAC#_____	_____	PSH ____ PSV ____ or SAC#____	___
leak or rupture		FSV ____ PSL ____	____	ESD	

Notice that the API SAC checklist paragraph is cited on the above table when a particular protective device is **not** installed (usually because a redundant device is installed on a connected unit). The appropriate safety shutdown or activation device corresponding to the protective detection sensor is defined. Some protective devices, such as the pressure relief valve (PSV), combine both sensor and actuator

Appendix

API series 14, Offshore Safety and Anti-Pollution Recommended Practices

- API 14A, " Subsurface Safety Valve Equipment", provides minimum requirements for subsurface safety valves.
- API RP 14B, "Design, Installation, Repair, and Operation of Subsurface Safety Valve Systems".
- API RP 14C, "Analysis, Design, Installation, and Testing of Basic Surface Safety Systems on Offshore Production Platforms".
- API RP 14D, "Drilling and Production Equipment, Specification for Wellhead Surface Safety Valves and Underwater Safety Valves for Offshore Service".
- API RP 14E, "Design and Installation of Offshore Production Platform Piping Systems".
- API RP 14F, "Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified Locations".
- API RP 14G, "Fire Protection and Control on Open-Type Offshore Production Platforms".
- API RP 14J, "Design and Hazard Analysis for Offshore Production Facilities", First Edition (September 1993).

Legislation Governing Oil and Gas Activities in the UK Sector of the North Sea

- 1934 – Petroleum Production Act.
- 1962 – Pipelines Act.
- 1964 – Continental Shelf Act.
- 1971 – Mineral Workings (Offshore Installations) Act.
- 1972 – Prevention of Oil Pollution Act.
- 1975 – Petroleum & Submarine Pipeline Act.
- 1992 – Offshore Safety Act.
- 1992 – Offshore Safety (Protection Against Victimization) Act.

Regulations Were Created Based Upon the above Legislation.

- 1972 – SI 703 – Offshore Installations (Managers) Regulations.
- 1973 – SI 1842 – Offshore Installations (Inspectors & Casualties) Regulations.
- 1974 – SI 289 – Construction & Use.
- 1976 – SI 1019 – Operational Safety, Health, & Welfare.
- 1976 – SI 1542 – Emergency Procedures.
- 1976 - SI 923 – Submarine Pipelines & Diving Operations.
- 1977 – SI 46 – Livesaving Appliances.
- 1978 – SI 611 – Firefighting Equipment.
- 1978 – SI 1759 – Well Control.
- 1981 – SI 399 – Diving Operations.
- 1989 – SI 1029 – Emergency Pipeline Valve.
- 1989 – SI 971 – Safety Representative & Safety Committees.
- 1992 – Safety Case.