An Application of Risk-based Design Criteria: HF Alkylation Rapid Acid Deinventory System

Stephen D. Unwin, Ph.D.
Unwin Company
1920 N.W. Blvd, Suite 201
Columbus, Ohio 43212

Robert R. Roberts
Roberts and Roberts

Paper presented at the 1st Annual Symposium of the Mary Kay O'Connor Process Safety Center, "Beyond Regulatory Compliance, Making Safety Second Nature",
George Bush Presidential Conference Center, College Station, Texas
March 30-31, 1998.

AN APPLICATION OF RISK-BASED DESIGN CRITERIA:

HF ALKYLATION UNIT RAPID ACID DEINVENTORY SYSTEM

Stephen D. Unwin

Unwin Company, 1920 Northwest Blvd., Suite 201, Columbus, Ohio 43212

(614) 486-2245, email: s.unwin@mci2000.com

Robert R. Roberts

Roberts and Roberts, 8642 Villa La Jolla Drive, Suite 6, La Jolla, California 92037

(619) 558-2197, email: rrobert1@san.rr.com

INTRODUCTION

The value of systematic, hazard identification techniques in the management of operational safety has been demonstrated to many through practical experience. What may have initially been a regulatory burden to certain companies seeking compliance with the OSHA PSM Standard has proven to become a central, practical basis for decision-making. Furthermore, an insight finding growing acceptance is that relatively small enhancements in the technical risk-basis for a process hazard analysis (PHA) method can result in disproportionately greater return in terms of its value as a decision tool. Application of quantitative risk assessment, though not specifically demanded by PSM, is a refined form of PHA that can provide robust, defensible bases not only for safe process operation, but also for safe process design.

Since prior to introduction of the PSM Standard, the west coast refinery that is the subject of this paper has adopted quantitative risk and reliability assessment techniques as a cornerstone of its risk management program. This has resulted not only in a better understanding of the sources of risk, both to safety and good business, but also in the risk-informed allocation of limited resources.

The refinery currently operates a Hydrogen Fluoride (HF) Alkylation Unit. An Acid (HF) Isolation and Evacuation System (AIES) was installed at the unit to mitigate the unlikely event of a significant acid leak. Three AIES design options were originally identified, each with distinctive characteristics in terms of accident mitigation capability and reliability. Selection among the AIES options was based on a detailed, comparative assessment of operational risk. The assessment had three principal objectives:

1. Quantify the accident risks associated with each of the three AIES design options,
2. Identify those design and operational characteristics of the options that distinguish them from the perspective of reliability and risk, and
3. Based on comparison of the three risk profiles, provide a robust technical basis for identifying the preferred option for implementation.

This paper describes the methods used in the risk-based design selection.

A backdrop to the study was a proposed local regulatory requirement affecting the operation of processes using HF. The rule would have required the installation and maintenance of an automated system which, in the event of an accidental HF release, is capable of evacuating the HF inventory to an HF-dedicated emergency holding vessel outside the unit battery limits. This proposed requirement was based on guidance in API Recommended Practice 751 [1]. This particular approach to accident mitigation was among the AIES options considered.

Three design options were identified. Each was distinctive in terms of its capability to mitigate accidents of various severities, and its functional reliability.

Option 1:

Option 1 reflected the system characteristics required by the proposed regulation in which a vessel dedicated to receiving evacuated acid during emergency deinventorying is located outside the unit battery limits. The system is designed to mitigate a process break (i.e., leak or rupture) in one of the five high-acid bearing sections of the unit:

1. Fresh Acid Storage Section
2. Reactor #1 Section
3. Reactor #2 Section
4. Acid Settler #1 Section
5. Acid Settler #2 Section

On detection of an HF release through HF alarm or visual means, the AIES is actuated by push button in the control room. The appropriate mode of AIES response depends on the location of the break; therefore, correct diagnosis of the location is critical. The mode of AIES actuation dictates the transfer positions of motor-operated valves (MOVs) in the system, determining which unit section is evacuated and the acid evacuation route. The MOVs are output devices on a programmable logic controller (PLC).

If the release is from the acid storage section, acid is transferred to the emergency holding vessel by a pump which is cold-started as part of AIES actuation. If the release occurs elsewhere, the acid is evacuated under system pressure to the holding vessel. This requires the isostripper sidecut pump, which circulates hydrocarbon to the acid sections, to remain running throughout the evacuation mission.

Option 2:

Option 2 differed significantly from Option 1 from both design and operational perspectives. First, the HF Alkylation Unit is converted from the Series Recycle Configuration (SRC, the existing configuration prior to installation of the AIES, which is retained in Option 1) to the Series Acid Configuration (SAC). The distinction between these configurations is:

SRC: The Reactor #1 - Settler #1 circulation loop is connected serially with the Reactor #2 - Settler #2 circulation loop. In effect, there are two acid circuits.

SAC: The two reactors and two settlers are all connected serially, resulting in a single acid circuit. This reduces the amount of pipework in the SAC configuration, particularly through absence of the pipework intended in the SRC to allow acid transfer between two circulation pools. It also removes the need for one of two acid circulation pumps.

A further distinguishing feature of Option 2 is that it excludes a dedicated emergency acid holding vessel. The response to a break in the HF Alkylation Unit is:

1. On detection of an HF release through HF alarm or visual means, the immediate response is to isolate all the acid-holding vessels and the single active acid circulation pump by push button in the control room. This single push button actuates a series of MOV transfers. If the leak occurred in unit pipework (pipes, valves, or flanges), a reactor cooler, or the circulation pump, then this action would be sufficient to arrest the release.

2. If the release is subsequently diagnosed to be in one of the high-inventory vessels (i.e., an acid settler, or the acid storage vessel), then the acid inventory of the affected vessel is transferred to an unaffected settler. Each settler has the capacity to hold the acid inventory of the unit. Evacuation of the affected vessel would be initiated from the board. If the release occurs in one of the settlers, then the acid circulation pump needs to be warm-started (having been shut-down during isolation) to effect the transfer to the other settler. If the release occurs in the acid storage vessel, then a dedicated acid transfer pump must be cold-started to effect the transfer.

Option 3:

This final option combined features of the two previous options. As in Option 2, the unit is redesigned to the Series Acid Configuration in which the two settlers and two reactors are part of a single acid circulation pool. However, as in Option 1, the AIES is equipped with a dedicated emergency holding vessel located outside the unit battery limits. As in Option 1, the response to a break in any one of the five unit sections is evacuation of the affected section to the acid holding vessel.

RISK ASSESSMENT AND RISK MANAGEMENT RESOURCES

The collection and analysis of equipment reliability data is an important element of the refinery’s risk management program. These data provide a basis for

(a) tracking the impact of risk/reliability management practices, and

(b) predicting the risk and reliability characteristics of safety-critical and production-critical refinery units.

The data reflect operational experience extracted from the work order system for the period 1981 to 1994. Analysis of these data has been the basis for the estimation of component failure rates of equipment in HF service, including leak initiation frequencies in various equipment types.

In combination with the risk and reliability models of the optional AIES designs, these data provided the basis for the comparative reliability/risk study.

RISK ASSESSMENT METHODS

The risk considered in each AIES option was that of a break (leak or rupture) in the process boundary that (a) the AIES is unable to mitigate because of limitations in system capability, or (b) the AIES fails to mitigate because of equipment failures and/or operator errors. The study involved systematic modeling of equipment and human factors influencing (1) the likelihood of a scenario demanding actuation of the AIES, and (2) the capability and reliability of AIES response.

Understanding the capability of each AIES option is a prerequisite to modeling the system's reliability, i.e., the probability that the system will realize its capability.

Capability of Systems

Each AIES option, like any system, has limited capability. The capability of the AIES is limited by its speed of response. Response speed is dictated by

(a) the time lapse between initiation of the break and actuation of the system by the operator

(b) the time taken for the system MOVs to transfer position

(c) the time taken for the evacuation or transfer pumps to start up and

(d) the time to complete acid evacuation or transfer.

The type of system response to an HF release is determined by the option under consideration and the location of the release. The three general types of AIES response are:

(1) Break Isolation: Applies to Option 2 for pipe, flange, valve, reactor cooler, and pump breaks - The major acid holding vessels are isolated.

(2) Acid Transfer: Applies to Option 2 for breaks in the settler and storage vessels - Acid is transferred from the affected vessel to an unaffected settler.

(3) Acid Evacuation: Applies to Options 1 and 3 for all breaks - Acid is evacuated from the affected unit section to the emergency acid holding vessel located outside the unit battery limits.

The AIES system mission was defined as that of reducing the magnitude of an HF release to 1500 gallons or less. This release size was assessed to be within the mitigation capability of the water spray capacity at the unit. Based on estimation on the release rates associated with various leak sizes and realistic assessments of operator and equipment response times, the following system capabilities were deduced:

(a) Isolation mode: The AIES is capable of mitigating breaks of hole size-equivalent 1.5" (i.e., equivalent to a guillotine break in a 1.5" ND pipe) and less

(b) Transfer mode: The AIES is capable of mitigating breaks of hole size-equivalent 1" and less

(c) Evacuation mode: The AIES is capable of mitigating breaks of hole size-equivalent 1" and less

The subsequent steps in the risk study were to:

1. Characterize the range of hypothetical HF release events in terms of release location and release size

2. For each hypothetical release scenario, determine whether each AIES design is capable of mitigating the release

3. For each mitigatable release, determine the reliability of the AIES

4. Define the risk associated with each AIES option in terms of the likelihood of an *unmitigated* release, which combines (a) the likelihood of an *unmitigatable* release (i.e., one that due to its size and location is beyond the mitigation capability of the AIES), and (b) the likelihood that a *mitigatable* release occurs but the AIES fails to perform its function due to limited reliability.

Form of the Risk Model

The model has two components: (1) the initiating event model, and (2) the AIES response model. The initiating event model delineates potential HF release scenarios (in terms of size and location) and estimates their likelihoods as annual probabilities. The response model delineates potential modes of AIES failure and their likelihoods, i.e., their conditional probabilities given a demand on the system. These two models are integrated to estimate the overall likelihood of the event that an HF release occurs *and* the AIES fails to mitigate it, i.e., fails to limit the release to less than 1500 gallons.

Expressed mathematically, the annual probability of an unmitigated HF release is equal to

Prob

$$= 3_{mn} (I_m \times A_{mn}) + 3_i J_i \quad (1)$$

where I_m and J_i, estimated from the initiating event model, are defined as

I_m = The annual probability with which a mitigatable initiating event m occurs. Initiating events are categorized with respect to the section of the unit in which the release occurs, the component type in which it occurs (valve stem, flange, line weld, vessel, pump seal, or pump casing), and whether the release results from a component leak or rupture.

J_i = The annual probability with which an unmitigatable initiating event i occurs, i.e., an event beyond the design capability of the AIES.

A_{mn}, estimated from the AIES response model, is defined as

A_{mn}= The probability, given the occurrence of a mitigatable initiator m, that the AIES fails in failure mode n, e.g., the acid evacuation path fails to open on demand due to failure of a specific MOV to transfer position.

Each *mn* combination and each single *i* value defines one complete accident scenario. This formula provides the basis for determining the contribution of individual process leak/ rupture events and modes of AIES failure to the overall release probability for each AIES option.

The operational risk associated with limited reliability and/or capability of each AIES option is defined as the product of the HF release probability and the consequence severity of the release:

$$R = \sum_{mn} (I_m \times A_{mn} \times C_m) + \sum_{i} (J_i \times D_i) \quad (2)$$

where R is the risk parameter, C_m is the consequence severity of release initiating event m if left unmitigated, and D_i is the consequence severity of the unmitigatable initiating event i.

A detailed consequence analysis of each scenario was considered unnecessary for the purposes of comparing the AIES options since only the relative risk between options was of interest. It was necessary to choose a consequence parameter that reflected the relative consequence potential of various release scenarios and would also be sensitive to any distinctions between AIES designs with respect to the distribution of accident consequence severities (due to, say, the distribution of pipe diameters). The consequence parameter selected was the HF release rate associated with each release scenario.

Initiating Event Model

Process isometrics and P&IDs formed the basis for identifying potential HF release sites. A spreadsheet was developed to tabulate the component counts in each piping run for both the SRC configuration (underlying Options 1) and the SAC configuration (underlying Options 2 and 3). With each piping run we associated a number of pipe welds, valves (check, control, and block), and flanges. Vessels, vessel flanges, and pumps were also counted in each of the two alternative configurations.

Two types of release event were defined for each component site:

(a) a rupture, assessed for each pipe component to be equivalent to a full guillotine break in the parent piping run.

(b) a significant leak, assessed conservatively for each pipe component to be equivalent to a full guillotine break in a piping run of 50 percent diameter of the parent piping run.

All vessel body ruptures were assumed to be unmitigatable.

The initiating event model spreadsheet was developed to combine individual component release frequencies to determine the overall likelihood of a release for a given release size, release location, or component type.

The initiating event model was expanded to include pump seal leaks associated with failures in the seal flush system. Causes included plugged filters and various operator/maintenance errors.

AIES Response Model

Between the three system options, 14 modes of AIES response to a unit boundary failure were identified:

<u>Options 1 and 3:</u> The mode of AIES response in Options 1 and 3 depends on the location of the release. The location dictates the unit success criteria in terms of MOV position transfers necessary to establish and isolate the acid evacuation path to the remote acid holding vessel. The break location also determines whether acid evacuation can be effected under system pressure or, in the case of a break in the fresh acid storage section, an emergency evacuation pump must be started-up.

<u>Option 2:</u> In this option the immediate operator response, regardless of the release location, is the single push-button isolation by MOVs of the major acid holding vessels and the acid circulating pump. Identification of the release location by the operator is unnecessary for this immediate response. The system success criteria, i.e., the minimal number of MOVs that must successfully transfer position, depends on the break location.

This single operator response mode is adequate except in the unlikely event that the break occurred within the isolating valves of a major vessel. In this case, the subsequent system response is to transfer the acid inventory of the affected vessel to an unaffected acid settler vessel.

Table A summarizes the AIES response modes (in terms of the release sites which determine the required AIES response) for each design option. The failure probabilities (unavailabilities) for each mode are also shown in the table. A discussion of model quantification will follow.

TABLE A

AIES RESPONSE MODES

AIES OPTION	**MODE**	**RELEASE SITE**	**UNAVAILABILITY**[a]
OPTION 1	1	Acid Storage Section	1.21E-1
	2	Reactor No. 1 Section	7.09E-2
	3	Reactor No. 2 Section	7.09E-2
	4	Acid Settler No. 1 Section	7.56E-2
	5	Acid Settler No. 2 Section	7.56E-2
OPTION 2	1	Line or Reactor Vessel	2.85E-2

	2	Acid Circulation Pump	9.54E-3
	3	Acid Storage Vessel	1.03E-1
	4	An Acid Settler Vessel	6.66E-2
OPTION 3	1	Acid Storage Section	1.21E-1
	2	Reactor No. 1 Section	7.09E-2
	3	Reactor No. 2 Section	7.09E-2
	4	Acid Settler No. 1 Section	6.62E-2
	5	Acid Settler No. 2 Section	6.62E-2

a Probability of AIES failure given the event of a mitigatable release

The response of the AIES was modeled using reliability block diagram (RBD) techniques. An RBD was developed for each AIES response mode to define the engineering logic connecting operational events, such as equipment failures and operator errors, to the event of AIES failure.

Typical operational events addressed were HF detector failure, operator failure to detect a release or to correctly diagnose its location, failure of pumps to start or run throughout their required mission, and failure of MOVs to transfer position on system actuation.

The RBD modeling process for each AIES response mode involved, first, resolution of the event of AIES failure to its immediate causes. These immediate causes were represented as event blocks *nested* in the top-level event of AIES failure. In general, event blocks are related to the event in which they are nested (i.e., the parent event) through either OR logic or AND logic. OR logic indicates that any one of the nested events is sufficient to cause occurrence of the parent event. Such nested events would be represented as serial blocks. For example, a valve may fail to close on demand (parent event) if there is a hardware failure of the valve (first nested event) OR the operator fails to actuate the valve (second nested event).

AND logic indicates that all the nested events must occur to cause occurrence of the parent event. Such nested events would be represented as parallel blocks. For example, there may be failure to isolate a vessel (parent event) only if isolation valve #1 fails to close (first nested event) AND isolation valve #2 fails to close (second nested event). Figure A shows an example of an event block and its nested blocks extracted from the reliability model.

Once the event of AIES failure was resolved to its immediate causal events, each of *these* causal events was then resolved to *its* causes through nested logic. This process was repeated until the *basic event* level was reached. Basic events are the stopping point of the model. Each basic event corresponds either to the failure of an item of hardware in a specific failure mode, such as a stuck open valve, or to a human error, such as failure to follow a specific operating procedure.

An RBD encodes similar information to a fault tree. However, an RBD has the property that each single path (left to right) through the diagram corresponds to a success path of the system in the following sense: If none of the failure events defined along the path occur, then the AIES has met its success criteria.

Once the RBD was finalized, each basic event was quantified by its probability of occurrence. Depending on the nature of the basic event, its probability of occurrence is a specific function of (1) reliability parameters such as equipment failure rates and human error rates, and (2) unit-specific operational information such as equipment test and maintenance intervals, mean repair times, and equipment mission times. These operational data were developed to reflect current or anticipated practices at the refinery.

Solving the RBD involves the generation of so-called failure *(minimal) cut-sets* or *scenarios*. Using logic algorithms, the RBD software "condenses" a series of cut-sets from the RBD. Each cut-set is a minimal combination of basic events that is sufficient to cause AIES failure. Table B shows typical failure cut-sets for a single AIES response mode. Table A summarizes the total failure probability (i.e., the summed probability of all contributing cut-sets) for each AIES response mode.

TABLE B

EXAMPLE AIES FAILURE CUT-SETS

AIES
OPTION: 3

RESPONSE

MODE
FOR:
RELEASE
IN ACID
STORAGE
SECTION

TOTAL
FAILURE
PROBABILITY
= 1.21E-01

CUT-
SET
DESCRIPTION
BE
PROB[a]
CS
PROB[b]

1
PEVAC-
STFL
Evac
Pump
PEVAC
Fails
to
Start
from
Cold
6.46E-
02
6.46E-
02

and Evac Acid from Storage Section

2
H-
DET-
HFOK-
OP1/3
Operators
Fails
to
Detect

Release
Given
3.67E-
02
3.67E-
02

HF Detector Alarm

3
HF-
DET-
FL
HF
Detectors
Fail
to
Respond
to
Release
1.98E-
01
9.41E-
03

H-
DET-
HFFL-
OP1/3
Operators
Fail
to
Detect
Release
Given
4.75E-
02

HF Detector Failure

4
MOV-
J-
FC
MOV
J
Fails
Closed
5.09E-
03
5.09E-

03

5
MOV-K-FC
MOV K Fails Closed
5.09E-03
5.09E-03

6
H-MOV-DIS
Failure to Reconnect MOV Power After
3.00E-03
3.00E-03

PLC Logic Test

7
H-XFER-OP1/3
Operator Fails to Diagnose Release Location
2.67E-03
2.67E-03

and Initiate Evacuation

a Probability of basic event given demand on AIES

b Probability of cut-set (= product of constituent basic event probabilities) given demand on AIES

RELIABILITY DATA

Failure rate data used to quantify both the initiating event model and the AIES response model were based on the refinery's operational data, supplemented where necessary by generic industry data. As part of its risk management initiatives, the refinery has assembled a database of HF equipment performance history based on work order data.

The high degree of model resolution (individual piping runs and associated components are identified in the model) demanded that equipment leak frequencies be estimated as a function of individual component type (weld, flange, pump, vessel, or valve type) and parent line size (nominal diameter).

Where failure data were sparse, particularly for more severe and less likely modes of equipment failure, then techniques were developed to estimate equipment failure rates based on data describing degraded component performance prior to replacement or corrective maintenance. These techniques involved estimating the probability of failure to detect degraded equipment conditions before functional failure. The techniques were applied to the assessment of pipe failure rates based on line replacement data (associated with small or imminent line leaks) extracted from the work order system.

In circumstances where limitations in maintenance data precluded application of this technique, a *Bayesian* analysis was conducted in which generic failure rate estimates were systematically modified to reflect the number of occurrences of related component failures in the refinery's operating history.

RESULTS

A variety of insights and results could be extracted from the integrated model. For example, the overall likelihood of an HF release could be attributed to

1. various equipment sources (e.g., block valves, piping welds, flanges, pump seals),

2. various locations within the unit (e.g., acid storage section, reactor #1 section), and

3. various release sizes (e.g., 2" breaks, 1" breaks).

Also, the roles of various equipment items and operator actions in determining the overall reliability of the AIES could be established. The principal result categories (risk measures) with respect to which the importance of individual release sites and AIES failure modes were assessed are:

Release Frequency:

The frequency (annual probability) which a process boundary break occurs

Unmitigatable Release Frequency:

The frequency with which a release occurs that, due to its size and location, is beyond the mitigation capability of the AIES

Unmitigated Release Frequency:

The frequency with which a release occurs that is either *unmitigatable* or, although within the mitigation capability of the AIES, fails to be mitigated due to the limited reliability of the AIES

AIES Unavailability:

The overall *unavailability* of the AIES is the fraction of mitigatable releases that the AIES would fail to mitigate due to equipment failure or human error.

That is, it is a measure of the unreliability of the system.

Risk:

Risk is defined as the annual expectation value of the consequence severity (see Equation 2). The HF release rate is the surrogate consequence measure for each accident scenario (see previous discussion).

Table C summarizes the quantitative estimates of these risk measures for each of the three AIES options.

TABLE C

AIES RISK COMPARISONS

RISK PARAMETER	**AIES OPTION**[a]		
	Option 1	Option 2	Option 3
Release (IE) Frequency[b]	**1.8E-1**	**9.2E-2**	**9.2E-2**
Unmitigatable Release Frequency[c]	**6.6E-4**	**4.4E-4**	**4.8E-4**
Unmitigated Release Frequency[d]	**1.4E-2**	**1.6E-3**	**6.6E-3**
AIES Unavailability[e]	**7.6E-2**	**1.2E-2**	**6.7E-2**
Risk[f]	**1.5**	**0.51**	**0.87**

a Option 1: SRC with emergency acid evacuation to dedicated vessel

Option 2: SAC with isolation and intra-unit acid transfer

Option 3: SAC with emergency acid evacuation to dedicated vessel

b All frequencies are annual

c Incidents beyond AIES mitigation capability

d Incidents that the AIES fails to mitigate, including unmitigatable breaks

e Fraction of mitigatable releases that the AIES fails to mitigate

f Annual expectation value of consequences

CONCLUSIONS

Table C shows Option 2 to be the most attractive from the perspective of all the risk parameters. Understanding the better risk/reliability performance of Option 2 requires inspection of the detailed model results. These results reveal the roles of equipment, system design features, and operational strategies in establishing the overall likelihood of an acid release and the capability/reliability of the AIES. Key insights are:

1. Option 2, based on the Series Acid Configuration (SAC) of the HF Alkylation Unit, has a single active acid circulation pump while the Series Recycle Configuration (SRC) of Option 1 has two circulation pumps. Since pump seals and casing are dominant contributors to the overall likelihood of an acid release, removal of a pump reduces risk significantly. Option 3, also based on the SAC, shares this advantage.

2. The AIES in Option 2 has the greatest reliability of the three options. This is due principally to the fact that mitigation of the most likely release scenario (pump tandem seal or casing failure) demands only isolation of the pump through MOV closure. Furthermore, there is redundancy in the MOVs (all of which close on system actuation) that can isolate the pump from major acid inventories. Mitigation of a release from any other location in Option 2, with the exception of the settler vessels or the acid storage vessel, requires only isolation of the unit vessels.

In contrast, the reliability with which the AIES would be actuated successfully in Options 1 and 3 is limited by the need to evacuate acid to a remote holding vessel, requiring the transfer of multiple MOVs and, depending on release location, the cold-startup of an evacuation pump.

Extensive sensitivity analyses, in which the values of key model input parameters were varied, indicated that these insights are robust in the sense that they are preserved under numerical variations within the range of technical uncertainties. Other factors favoring Option 2, but of less significance from the perspective of the risk differentials, are

1. Initial actuation of the Option 2 AIES requires no diagnosis of release location, i.e., all the vessels and the circulating pump are immediately isolated. Although subsequent diagnosis is necessary if the leak persists, i.e., if it occurs in a settler or the acid storage vessel, the relative likelihood of a vessel leak is small (less than one percent of total). In contrast, Options 1 and 3 require the section in which the release has occurred to be identified before actuating the system in order to evacuate the correct section. This introduces the potential for misdiagnosis of the leak location.

2. Absent in the SAC (but present in the SRC) are several piping runs which, by virtue of their size, are potential sites for a large release. In particular, the 2" piping run interconnecting the two acid circulation loops in the SRC is absent in the single-circuit SAC. This decreases the likelihood of an unmitigatable release in the SAC. Furthermore, the more rapid response times associated with isolation of a leak in Option 2 (versus acid evacuation in the other options) allows the mitigation of slightly larger leak sizes.

This quantitative risk/reliability study led to the conclusion that installation of a vessel dedicated to receiving acid evacuated from the HF Alkylation Unit is not the most effective means to control the risk of a significant HF leak. The conclusion was that a response strategy involving isolation of all major acid inventories in the unit and, if necessary, transferal of acid within the unit, results in greater risk reduction. This option was implemented.

Finally, we emphasize that the models and data used in this study were developed specifically for the alkylation processing unit of the subject refinery. The findings would not necessarily apply to alkylation units at other facilities.

REFERENCE

1. American Petroleum Institute, *Safe Operation of Hydrofluoric Acid Alkylation Units, Recommended Practice 751*, Washington DC, 1992