Integrity Operating Windows

API RECOMMENDED PRACTICE 584
FIRST EDITION, MAY 2014

AMERICAN PETROLEUM INSTITUTE

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Introduction

In today's operating environment, it is not enough to base future inspection plans only on prior recorded/known history of equipment condition. A fundamental understanding of the process/operating conditions and resulting damage mechanisms are required in order to establish and maintain an inspection program that yields the highest probability of detecting potential damage. Inspection plans should be dynamic and account for changing process conditions and current equipment condition. A fundamental step is to frequently rationalize and align the developed degradation knowledge base of the materials of construction with the operation of the equipment, its inspection history, measured corrosion rates and known industry problems. With the move to risk based inspection programs, it is even more vital to identify and track process information that validates or might cause changes to existing inspection plans.

In order to maintain the integrity and reliability of pressure equipment in the refining and petrochemical industry, several process safety management systems are necessary. Many of those management systems are oriented toward having a rigorous inspection program, as well as all the supportive engineering activities, to maintain pressure equipment integrity and reliability.

In addition to the application of industry codes, standards, and recommended practices, a number of other PSM systems are vital to support a rigorous inspection and mechanical integrity program in order to predict/avoid/prevent pressure equipment damage/corrosion; leaks and failures; and improve reliability. Three key elements of those supporting PSM programs include:

— the establishment, implementation, and maintenance of integrity operating windows (IOW's);

— an effective transfer of knowledge about unit specific IOW's to all affected personnel; and

— an effective MOC program to identify any changes to the process or the physical hardware that might affect the integrity of pressure equipment.

In order to operate any process unit, a set of operating ranges and limits needs to be established for key process variables, to achieve the desired results (i.e. product within specification, safe operation, reliability, etc.). These limits are generally called operating limits or operating envelopes. IOW's are a specific subset of these key operating limits that focus only on maintaining the integrity or reliability of process equipment. Typically IOW's address issues that involve process variables that, when not adequately monitored or controlled, can impact the likelihood and rates of damage mechanisms, which may result in a loss of containment.

For purposes of this document, maintaining the integrity of the process unit means avoiding breaches of containment, and reliability means avoiding malfunctions of the pressure equipment that might impact the performance of the process unit (meeting its intended function for a specified time frame). In that sense, integrity is a part of the larger issue of pressure equipment reliability, since most breaches of containment will impact reliability. IOWs are those preset limits on process variables that need to be established and implemented in order to prevent potential breaches of containment that might occur as a result of not controlling the process sufficiently to avoid unexpected or unplanned deterioration or damage to pressure equipment. Operation within the preset limits should result in predictable and reasonably low rates of degradation. Operation outside the IOW limits could result in unanticipated damage, accelerated damage and potential equipment failure from one or more damage mechanisms.

Pressure equipment is generally fabricated from the most economical materials of construction to meet specific design criteria based on the intended operation and process conditions. The operating process conditions should then be controlled within preset limits (IOW's) in order to avoid unacceptable construction material degradation and achieve the desired economic design life of the assets.

One of the simplest examples of IOWs is the establishment of fired heater tube temperature limits to avoid premature rupture or unplanned replacement of the tubes. For example, heater tubes that have an API 530, 100,000 hour design temperature of 950 °F (510 °C) would have an increasingly shortened service life if operated at temperatures above this design temperature. So when this limit (950 °F) is exceeded, operators would be directed to adjust fired heater controls to get the tube temperature back to below 950 °F (510 °C) within a preset amount of time. That limit of 950 °F (510 °C) would be an IOW limit for those fired heater tubes. At an even higher temperature, say 1025 °F (550 °C), the operator might be directed to take more immediate actions to regain control or even shut down the fired heater. As such there may be more than one IOW limit for the same process parameter (in this case fired heater tube temperature), for tracking/trending or to gain control prior to reaching a critical IOW limit. In addition, there may be more than one predefined response, depending upon the degree of exceedance of the process parameter limit.

A properly structured, efficient, and effective inspection program depends on IOW's being established and implemented to improve inspection planning and to avoid unanticipated impacts on pressure equipment integrity. Inspection plans are typically based on historic damage mechanisms and trends and are not generally designed to look for unanticipated damage resulting from process variability and upsets. Inspection plans generally assume that the next inspection interval (calculated based on prior damage rates from past operating experience) are scheduled on the basis of what is already known and predictable about equipment degradation from previous inspections. Without a set of effective and complete IOW's and feedback loop into the inspection planning process, inspections might need to be scheduled on a more frequent time-based interval just to look for anything that might potentially occur from process variability.

Integrity Operating Windows

1 Purpose and Scope

1.1 The purpose of this recommended practice (RP) is to explain the importance of integrity operating windows (IOW's) for process safety management and to guide users in how to establish and implement an IOW program for refining and petrochemical process facilities for the express purpose of avoiding unexpected equipment degradation that could lead to loss of containment. It is not the intent of this document to provide a complete list of specific IOW's or operating variables that might need IOW's for the numerous types of hydrocarbon process units in the industry (though some generic examples are provided in the text and in Annex A); but rather to provide the user with information and guidance on the work process for development and implementation of IOW's to help strengthen the Mechanical Integrity (MI) program for each process unit.

1.2 The scope of this standard includes:

- definitions of IOW's and related terminology;
- creating and establishing IOW's;
- data and information typically needed to establish IOW's;
- descriptions of the various types of IOW's needed for process units;
- risk ranking IOW's;
- documenting and implementing IOW's;
- monitoring and measuring process variables within established IOW's;
- communication of IOW exceedances;
- reviewing, changing, and updating IOW's;
- integrating IOW's with other risk management practices;
- roles and responsibilities in the IOW work process; and
- knowledge transfer to affected personnel.

1.3 This RP outlines the essential elements in defining, monitoring and maintaining IOW's as a vital component of integrity management (materials degradation control) and assisting in the inspection planning process, including Risk Based Inspection (RBI). Other Process Safety systems may be affected by or involved with the IOW program, including management of change (MOC), process safety information (PSI), and training. For purposes of this RP, these systems are only addressed to the extent of mentioning the integration aspects that are needed with the IOW program.

The use of this RP for its intended purpose is entirely voluntary for owner-users. There are no requirements that any organization use it. It is intended to be useful to those organizations that wish to establish and implement IOW's.

1.4 This RP does not cover other operating windows established for normal process control for the purposes of maintaining product quality and other PSM issues including avoidance of operating error, that do not relate to control for the purpose of maintaining equipment integrity and reliability. However, IOW's should be integrated into existing systems for managing other operating variables and envelopes.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API 510, *Pressure Vessel Inspection Code*

API Recommended Practice 556, *Instrumentation and Control Systems for Fired Heaters and Steam Generators*

API 570, *Piping Inspection Code*

API Recommended Practice 580, *Risk-Based Inspection*

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1
alarms
Primary method of communication for critical IOW exceedances and some higher level standard IOW's.

NOTE Typically there would be an audible sound (e.g. horn, buzzer, beep, etc.) along with a visual signal (e.g. flashing light), in the control room that alerts operators to a deviation in a process condition that may require immediate attention.

3.2
alerts
A secondary level of communication to key stakeholders (i.e. operations, technical SME's) that signifies a condition that will need resolution to avoid a potential operating condition that could lead to process safety or reliability impacts.

NOTE 1 Generally, alerts can be addressed over a longer time period than alarms. Alerts may include visual signals, and/or audible sounds, and/or other real-time process tracking charts/graphs with limits identified, e-mail notifications, etc.

NOTE 2 For this RP, alerts are related primarily to standard IOW exceedances, but may also be implemented for Informational IOW's.

3.3
CCD
corrosion control document
Documents that contain all the necessary information to understand materials degradation issues in a specific type of operating process unit.

3.4
CLD
corrosion loop diagram
Drawings of portions of process units showing areas of similar corrosion mechanisms, similar operating conditions, and similar materials of construction.

3.5
CMD
corrosion materials diagram
A modified process flow diagram (PFD) showing equipment and piping corrosion mechanisms, operating conditions, and materials of construction in each portion of a process unit, as well as the usual PFD information.

3.6
IOW
integrity operating window
Established limits for process variables (parameters) that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined length of time (includes critical, standard and informational IOW's).

3.7
IOW critical limit
An established IOW level which, if exceeded, rapid deterioration could occur such that the operator must take immediate predetermined actions to return the process variable back within the IOW to prevent significant defined risks of potential equipment damage or hazardous fluid release could occur in a fairly short timeframe.

NOTE Other terminology has been used in place of critical limit, such as safe operating limit or safety critical limit.

3.8
IOW standard limit
An established IOW level defined as one that if exceeded over a specified period of time could cause increased degradation rates or introduce new damage mechanisms beyond those anticipated. Since the timing of the impact from an exceedance of a Standard IOW Limit can vary significantly, the notification and response to an exceedance can also vary. For higher risk exceedances, alarms or alerts are potentially needed and the operator may have some predetermined actions to take. For lower risk exceedances, alerts may only be needed for eventual interaction with operating supervisors or appropriate technical personnel and subject matter experts (SME's).

NOTE Other terminology for standard limits has been used such as key operating limit or reliability operating limit.

3.9
IIL
IOW information limit
An established limit or standard operating range for other integrity parameters that are used primarily by SME's (e.g. process engineer, inspector, corrosion specialist, etc.) to predict and/or control the longer term integrity/reliability of the equipment. These "Informational" IOW's are typically only tracked by the appropriate SME's and may or may not have alarms or alerts associated with their exceedances. In some cases the Informational IOW's are used for parameters that cannot be directly (or indirectly) controlled by operators, whose primary duty would be to make sure any exceedances are communicated to the designated SME for attention and corrective action, if any.

NOTE Other terminology can be used in place of an informational limit, such as corrosion control limit or reliability limit.

3.10
MOC
management of change
A documented management system for review and approval of changes in process, equipment or piping systems prior to implementation of the change.

NOTE For purposes of this RP, MOC may apply to making changes to or creating IOW's.

3.11
MI
mechanical integrity
The management systems, work practices, methods, and procedures established in order to protect and preserve the integrity of operating equipment i.e. avoid loss of containment due to the effect of equipment damage mechanisms. MI is typically one part of a process safety program.

3.12
notifications
A message to an operator and/or SME that an IOW exceedance has occurred which may not necessarily have an alarm associated with it, but may require a specific required action and response from an operator or SME.

3.13
PFD
process flow diagram
A simplified diagram of a process unit showing the main pieces of equipment and piping, with limited details of process design parameters.

3.14
PHA
process hazards analysis
A work process to assess and document the hazards and risks associated with operating a process unit, and to make recommendations on what actions may be necessary to mitigate unacceptable risks.

3.15
process variables
Parameters of the process fluids (chemical and physical) that need to be controlled.

3.16
PSM
process safety management
The implementation of all the work practices, procedures, management systems, training, and process safety information that are necessary in order to prevent the release of hazardous substances from process equipment.

3.17
pressure equipment
Stationary, static, or fixed equipment for containing process fluids under pressure, which for the purpose of this document does not include rotating equipment.

EXAMPLE Pressure equipment includes, but is not limited to such items as piping, vessels, heat exchangers, reactors, tanks (static head pressure), pressure relief devices, columns, towers, heater tubes, and filters.

3.18
RBI
risk-based inspection
A risk assessment and management process that is focused on inspection planning for loss of containment of pressurized equipment in processing facilities, due to material deterioration. These risks are managed through inspection and IOW monitoring in order to influence the probability of failure.

3.19
SME
subject matter expert
One who has in-depth knowledge and experience on a specific subject as it relates to IOW's.

NOTE Various types of SME's are necessary in order to establish IOW's for each process unit, e.g. corrosion/materials SME, process SME, operations SME, equipment type SME, inspection SME, etc.

3.20
stakeholder
Any individual, group, or organization that may affect, be affected by, or perceive itself to be affected by the IOW issue.

3.21
TAN
total acid number
A measure of potential corrosiveness of hydrocarbon feed steams containing various organic acids.

3.22
work process
A series of activities or steps aimed at achieving a set objective, with inputs and outputs. e.g. the IOW work process to establish IOW limits on operating parameters.

4 Parameters that May Require Different Types of IOW's

4.1 Typically, IOW process parameters that may influence the mechanical integrity or reliability of the equipment fall into two categories, chemical and physical. The parameters noted below are not all inclusive, but provide examples of the potential process parameters that may need IOW's established in order to control degradation rates and/or avoid the onset on new damage mechanisms that might eventually lead to breaches of containment.

4.1.1 Chemical parameters are those that relate to the chemistry and fluid content of the process. Examples of chemical parameters include: pH, water content, acid gas loading, sulfur content, salt content, NH_4HS content, NH_3 content, TAN, acid strength, amine strength, inhibitor concentration, chloride contamination levels, oxygen content, etc.

4.1.2 Physical (mechanical, operational) parameters are those that are not chemical in nature, but include all other aspects of a process design that are vital to maintaining control within established design parameters. Examples of physical parameters include: various pressure and temperatures such as design, operating, partial pressures, dew points, dry points, heating and cooling rates, delta pressure, etc. In addition, there are flow rates, injection rates, inhibitor dosage, amperage levels for contactors, slurry contents, hydrogen flux, vibration limits, corrosion probe measurements, etc.

4.2 IOW's should be classified into different levels, distinguished by risk, in order to set priorities on notifications (including; alarms, alerts, and/or other notifications) and timing of actions to be implemented when IOW's are exceeded. In this RP, three primary levels of IOW's: "critical", "standard", and "informational", are described based upon the predicted change in damage rate to equipment during an exceedance and the ability of the operator to take corrective action.

4.2.1 A critical IOW level is defined as one at which the operator must urgently return the process to a safe condition and, if exceeded, could result in one of the following in a fairly short timeframe:

— larger and/or quicker loss of containment,

— a catastrophic release of hydrocarbons or other hazardous fluids,

— emergency or rapid non-orderly shutdown,

— significant environmental risk,

— excessive financial risk, or

— other unacceptable risk.

4.2.2 A standard IOW level is defined as one that if exceeded over a specified period of time, requires predetermined operator intervention or some other corrective action by a SME in order to bring the process back within the IOW limits in order to avoid one or more of the following to occur:

— eventual loss of containment,

— a release of hydrocarbons or hazardous fluids,

— unscheduled or non-orderly shutdown,

— a negative impact to the long term unit performance and its ability to meet turnaround run length, or

— unacceptable financial risk.

4.2.3 A third level of IOW's may be established that are Informational Limits. Most parameters that have defined IOW's are controllable, especially for Critical and Standard Limits, but some are not and may not have an immediate designated operator intervention assigned to them. Deviations from informational IOW's could eventually lead to accelerated corrosion or other damage over a longer period of time. These parameters which may not be controlled by operators still may need to be reported to, reviewed by, and trended by designated technical personnel (SME's). For example, these Informational parameters may provide secondary or circumstantial indication of active corrosion/erosion such as in an atmospheric overhead tower where the primary process control parameter for corrosion in the reflux may be the pH of the condensate, but a secondary informational parameter may be the iron content measured periodically by laboratory sampling. When exceedances of these informational parameters are reported, the appropriate SME's in turn may then specify that some type of engineering, process, or inspection activities be planned or adjusted in order to control the rate of deterioration and prevent unacceptable equipment deterioration over the longer term. These informational IOW's do not normally have alarms or alerts associated with exceedances. In most cases, the limits for informational parameters would be established to provide a point where the operator (or implemented software) would initiate a notification to the appropriate SME that some informational parameter has exceeded a limit. Informational IOW's would typically be associated with the following situations:

— would not be directly related to a potential loss of containment within the near term,

— provides for an secondary indication of operational performance or corrosion control issue, and/or

— used to track parameters that are not necessarily controllable by operators.

4.3 The primary difference between a critical and a standard limit is in the reaction time allowed to return the process to within the IOW limits. For critical limits, there will typically be visual and audible alarms for the operators and typically all Critical Limits would require specific predetermined actions to be taken by the operator to urgently return the process to within the IOW limits. In some cases there may also be instrumented shutdown systems that automate a sequence of steps to regain control of the process. For some standard limits, there may also be visual and/or audible alarms, depending upon the level of risk and required response time associated with the IOW. A risk assessment process such as that outlined in 5.8 and Section 6 can be used to determine the need for what alerts/alarms are appropriate for each IOW. Standard limits can in many cases be just more conservative limits set for operating parameters prior to reaching critical limits in order to provide the operator with more time and options to bring the process back within the IOW limit before the more urgent measures required for exceeding a critical limit must be implemented.

4.4 In addition to the predetermined operator intervention required for critical limits and potentially standard limits that are exceeded, notifications to specific designated SME's should be designed into the system, so that appropriate technical investigations and corrective actions can be implemented to prevent further exceedances and plan for necessary follow-up testing/inspection. These notifications should include designated inspectors and/or inspection and corrosion specialists in case inspection plans need to be adjusted, depending upon the magnitude of the exceedance or in case corrosion management strategies may need to be adjusted.

4.5 Figure 1 illustrates how various types of operating limits might create boundaries for any specific operating window. The middle zone between the standard limits (high and low) is the zone designated for achieving operational targets. Outside of those limits, operator intervention is generally required to return the process into this zone. Some limit ranges may not have an upper or lower boundary, depending on the variable. For example, heater tube-skin temperatures generally have upper limits, but most times has no lower limit.

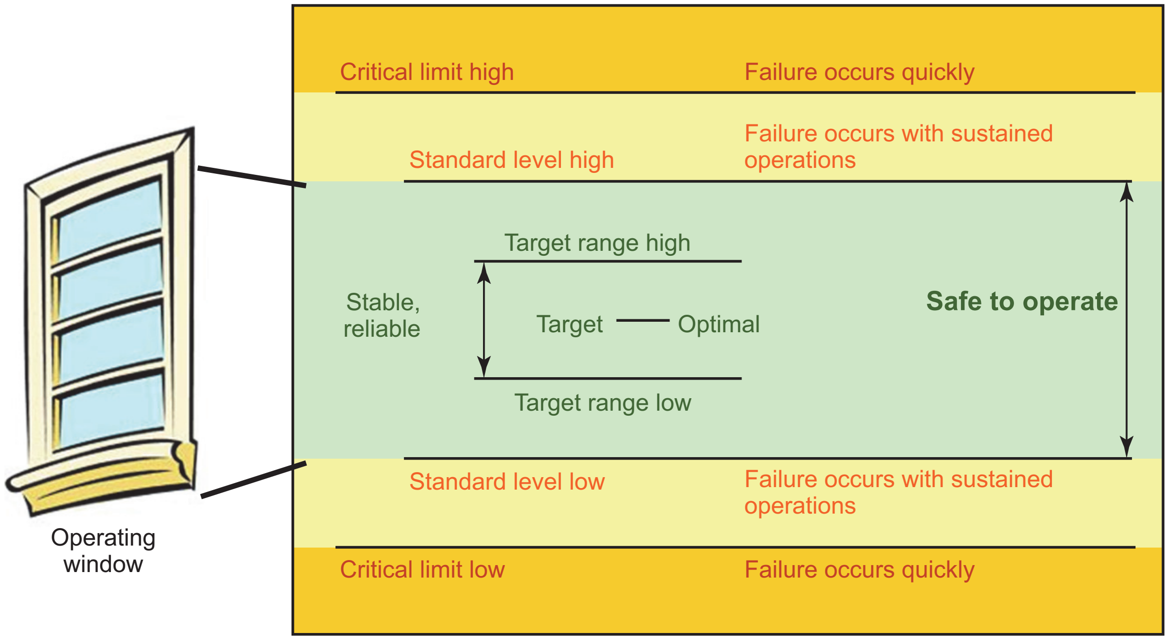


Figure 1—Zones of Operation Including Target Ranges with Standard and Critical Limits

5 IOW Work Process

5.1 In this section a general work process is outlined for identifying IOW's, setting appropriate limits relative to a defined premise and integrating IOW's into the site's mechanical integrity program. This process can be integrated into a review of existing IOW's to provide more focus on a longer term mechanical integrity perspective. Additional details on the type and levels of IOW's are outlined in Section 4 and Section 6. For a specific example that closely follows the flow outlined in this section for one specific piece of equipment, see Annex C. General guidance and considerations for identifying and setting appropriately conservative limits is outlined in Section 9. Note that this work process may be applied to a single equipment item, multiple equipment items in a group (corrosion circuit) or more generally to the overall process unit. A generalized flow chart for the overall work process is shown in Figure 2.

5.2 The first step in the process is to review the existing mechanical design conditions and prior operating conditions (normal, upset, start-up, shut-down, etc.). The identification of the likely or "active" damage mechanisms in 5.5 requires a fundamental understanding of the mechanical design, the process operating conditions (temperatures, pressures, service, inhibitors, etc.) and the materials of construction including the alloy and material grade, method of fabrication, prior thermal and mechanical treatments, etc. Consideration should be given to both the normal operation and any abnormal operation that could produce unanticipated damage mechanisms and/or accelerated damage rates. Other operating conditions such as startup, shutdown, catalyst regeneration, decoking, hydrogen stripping, etc. should also be considered.

5.3 The second step is to define any anticipated future unit/equipment operating conditions and establish a "premise" for establishing IOW limits. The premise is developed from the underlying assumptions which are agreed upon at the start of the IOW work process. These premises can include the level of risk that will be tolerated or the planned turnaround cycle for the unit or component. A premise may be established on an individual equipment basis

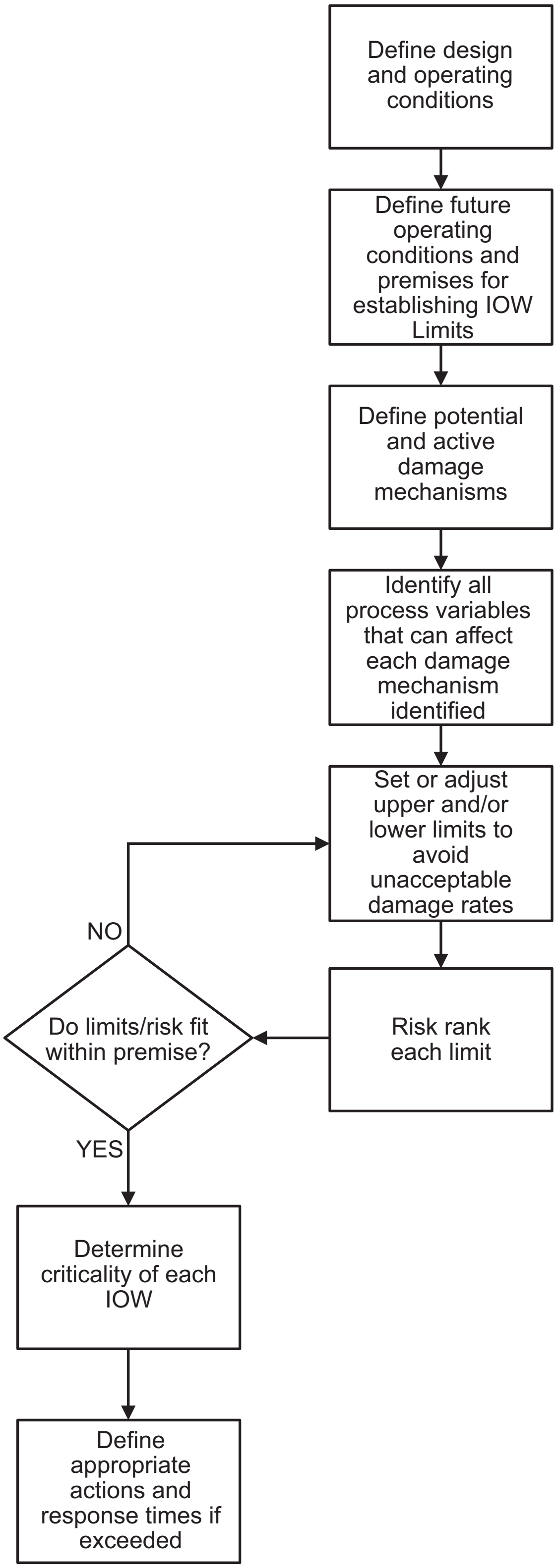


Figure 2—Suggested IOW Development Work Process

or on a unit specific basis. Any planned changes to the operation will need to be considered during the identification of the “potential” damage mechanisms that may be associated with those planned changes (e.g. higher sulfur in the feed stock to a refinery). A key consideration for establishing a premise is the time frame for which it will apply. In some cases, the established time frame may be very short (for a specific operation to take advantage of an opportunity feed stock for example), but in general, the time frame for setting damage limits should be based on an acceptable life for the equipment and/or the time period until the next turnaround. An example of this would be operating a heater to a higher than design tube metal temperature limit with the plan to retube this heater at the next planned outage. In some cases, setting the premise may lead to having to set limits on operating variables that may introduce a new damage mechanism, e.g. a limit may be placed on operating temperature in a hydrotreater in order to avoid high temperature hydrogen attack (HTHA). It is important that the consequences of all the premises be vetted and agreed upon by the IOW team.

5.4 The next step is to identify all of the active and potential types of damage mechanisms that could occur in each piece of process equipment. Determination of the historical damage rates for the equipment and predicted future rate considering any planned changes in operation should be made. Section 7 and Annex A contain examples of damage mechanisms and potential operating variables within process units that may need IOW’s established. There are several other sources of industry data that specifically identify typical damage mechanisms for various operating units. Specifically applicable to the refining and petrochemical industry is API 571 covering damage mechanisms and API 580 and API 581 covering Risk-based inspection. A list of common damage mechanisms is also provided in API 579/ASME FFS-1, Annex G. Specific operating site programs that have been utilized to identify/establish equipment specific damage mechanisms and/or risk that should be considered during this process may include the following.

— Risk-based inspection studies;

— Corrosion loop and circuitization programs or other unit corrosion reviews, such as establishing CCD’s;

— Equipment risk assessments;

— Process hazards analysis (PHA) or hazards analysis and operability (HAZOP) studies.

5.5 After identifying all applicable damage mechanisms, each key process variable related to activation of, or rate of progression of the damage mechanisms need to be identified. In many cases, there will be multiple, sometimes co-dependent operating variables that are required to produce the damage e.g. temperature, reactive sulfur content and alloy are co-dependent variables that affect the high temperature sulfidation rate. There may also be multiple variables, product/reactants, or other measurements that are indicators of the activity of a single specific damage mechanism, e.g. desalter efficiency, pH, chloride content, iron content, conductivity, salt point, dew point, and others are all indicators of corrosion potential in an crude unit atmospheric tower overhead system. The goal of the IOW program is not only to identify the key monitoring parameters but to also set limits around the most appropriate “controllable” parameters that can be adjusted by operations to achieve the desired level of equipment integrity and reliability. In general, the parameter that is most “controllable” and most effective at reducing the damage potential should be the primary variable for monitoring and applying limits. Other measurements or variables that are not primary indicators of damage may be considered as informational IOW’s.

5.6 Once the primary controllable operating variables/parameters have been identified, the next step in the process is to establish upper and lower limits to avoid unacceptable damage mechanisms/rates in relation to the inspection planning strategy. Previously existing limits should be reviewed against the defined premise to ensure they will achieve the desired level of reliability and mechanical integrity. There are multiple aspects to consider when establishing each of the operating limits as outlined in the following paragraphs.

5.6.1 The limit needs to consider the accuracy and relevance of the measurement, e.g. the measurement location may not be ideal relative to the damage location, the degree of measurement accuracy may require a more conservative limit being set to provide adequate response time if the measurement is not entirely accurate. The limit also needs to consider the rate of further damage progression expected at the limit level selected, i.e. how fast is the damage expected to progress, time to adjust the operation, and the potential effect on inspection planning strategy.

5.6.2 The limit needs to consider the rate of further damage progression expected at the limit level selected i.e. how fast is the damage expected to progress, time to adjust the operation and the potential effect on inspection planning strategy.

5.6.3 The limit needs to consider the level of risk for exceeding that limit. Setting a process limit will be related to the level of notification needed (alarm, alert, e-mail, or other notification) and related to the predetermined response actions when that limit is exceeded.

5.6.4 Consideration should be given to setting multiple limits on some IOW's to provide more time and less urgent responses to bring the operation back within normal operation before reaching a possible critical IOW limit. Some process variables could have an IIL at one limit that would provide time to an SME to consider an appropriate response, a standard IOW limit at a next level which may have a designated operator response, and ultimately a critical IOW limit which would require an urgent operator or automated response.

5.6.5 Some limits are not only a target value for a single parameter. Many of the corrosion related damage mechanisms also have a significant time element that needs to be considered. For the simple case of high temperature sulfidation, where temperature, alloy type and amount of reactive sulfur present in the process stream drive the corrosion rate; if a limit were to be set on temperature alone an exceedance may occur without any measurable damage to the equipment if there was insufficient time for measurable damage to occur.

5.7 In order to determine the level of the IOW (critical, standard or informational) a risk ranking process is useful. In some cases, the relative risk may be determined subjectively and in more complicated cases, the risk analysis may need to be more rigorous. Many operating companies have developed risk matrices and risk analysis procedures to provide guidance for consistent management decisions which may be used to determine the risk of exceeding the established IOW limit. For those who don't have one already established, an example risk matrix and analysis is provided in Section 6. Determining the IOW level and or risk for a given parameter is important to help distinguish which parameters and limits:

— will need alarms versus alerts;

— will need predetermined actions must be taken to speed recovery times;

— will need formalized follow-up and investigation after exceedances occur;

— if changed or adjusted may need to be managed through a MOC process, etc.; and

— will need a review of the inspection strategy by the inspector or SME.

5.8 Once the limits and relative risk ranking has been developed, the initially established limits should be compared to the original operating premise that was developed. The risk level for each parameter is often dependent (or co-dependent) on multiple factors and may need to be developed through an iterative process. In some cases, the existing sample points, instrument ranges, frequency of data acquisition, etc. may not be optimal in which case the assumed risk based on that measurement limit may be higher than is desirable. The intended business objectives for the run period also need to be considered, achieving product yields or production rates may require a compromise for some of the IOW limits, provided the risks associated with such compromises are acceptable to all stakeholders. In reality, this iterative process may be accomplished intuitively during the risk ranking process by continually testing a proposed limit level against the risk assumed at that level.

5.9 After establishing the limits and risk, the level of IOW (critical, standard, or informational) can be set. As noted in 5.8, the selected level of IOW is used to distinguish which parameters and limits will need alarms, alerts or other type of notifications, as well as the required response actions and timing, per 5.11. The level is also linked to the need to determine the amount of documentation required, ownership of the IOW and necessary follow-up on exceedances that have been recorded.

5.10 The last box in the flow chart in Figure 2 is to determine the appropriate actions that need to be taken and response timing for each IOW exceedance. Critical IOW exceedances will normally require an urgent specific response by the operator to avoid more rapid equipment degradation problems. Standard IOW exceedances will vary in their response actions and timing and will be less urgent than those associated with critical IOW exceedances. Response times for both critical and standard IOW's should be defined and agreed upon by the IOW team. Some of those actions will likely be for operators, but other response actions may be for inspectors and/or designated SME's. Response actions and associated timing by operators for IIL's will generally be mostly related to which inspector or SME should be notified in order to determine what response action is needed, if any, over the longer term. The notification of and follow up action by the inspector or SME is the essential step in linking applicable IOW exceedances to the MI program and inspection planning process.

6 IOW Risk Ranking

6.1 In this section, an example risk ranking process and risk matrix is provided to guide the user through a relative risk evaluation on the importance and priority of each parameter/limit combination under consideration. As noted in Section 5, IOW's may be risk ranked in order to help determine the appropriate priority of alarms, alerts and notifications to operating personnel and SME's, as needed and/or specified by the IOW response action. This risk assessment will also help to determine what actions the operator needs to take and how fast the operator needs to act before the process gets too far out of control, i.e. the higher the risk, the sooner the operator may need to respond and the more definitive the response may need to be. Additionally the higher the risk the more levels of action might be designated for Standard IOW's in order to provide the greatest chance of regaining control before a Critical level of alarm is reached. See Figure 6 showing an example where there might be more than one standard limit for tube-skin temperature IOW's before reaching a critical IOW limit.

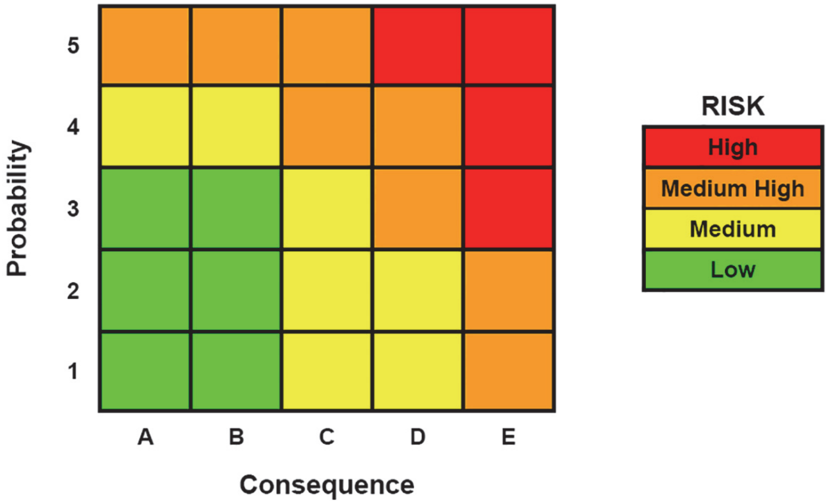
6.2 The risk of the established limits for a given operating parameter is a function of the event probability and consequence (i.e. risk) when the limit is exceeded. In each case or scenario there will be a number of risk sub-factors that need to be considered when establishing the risk levels which will be related to the probability of the event and the potential consequence if the event occurs. An approach to establishing three levels of IOW's ("critical", "standard" and "informational" limits) is outlined in order to separate IOW's for process parameters that may have shorter term mechanical integrity implications from those that have longer term process safety or reliability implications. After designating the highest risk IOW'S, i.e. critical limits, additional prioritization can be achieved through risk ranking of the "standard" and "informational" limits in order to identify those limits that need quicker, more definitive action by the operator or designated SME from those where there is more time to react to the information.

6.3 Figure 3 and Figure 4 contain simplified examples of how a risk assessment matrix and process can be used to establish IOW's. Start by assuming a limit to a given parameter that may meet the premise established for the intended operating period. For that limit determine how likely and how quickly the component or equipment is to fail if that limit is exceeded. Also determine what the consequences are if failure does occur at the imposed limit level, i.e. small leak; big leak; immediate emergency; safety issue and size; environmental issue and size; reliability issue and size; etc. The product of these two factors (probability of failure and consequence of failure) is the risk of failure. In Figure 4, some suggested generic guidance, actions, involvement, and responses to different levels of risk are shown.

6.4 For a simple example of the use of this risk assessment approach, time is used in place of a probability of failure, where a probability of "5" = highly likely to fail within hours to days. For consequence of failure a combination of safety and business interruption will be used where the consequence of "D" = Significant exposure risk to personnel and potential loss of profit. This result would yield a "5D" category on the matrix in Figure 3 with a corresponding "high" risk. Using Figure 4, we determine that Critical Limits are required to be established with appropriate alarms where operators are required to take fairly urgent predetermined actions to return the process to normal operation. In addition, the appropriate SME's are notified for this parameter exceedance along with the operations supervisor.

6.5 A second example of the use of this risk assessment approach involves an unexpected process change that results in a likely to fail corrosion situation within a few months, if something is not corrected. So it's not immediately urgent, but clearly needs attention relatively soon. A probability of 4 is assigned. The consequence involves a big leak which would involve a possible environmental citation and business interruption, as well as undesirable media attention. A consequence of C is assigned, resulting in a 4C medium high risk on the matrix in Figure 3. Using Figure 4, Critical or Standard IOW's would be established and operators would have predetermined actions associated with the exceedance which would need to be implemented within the predetermined time and likely also a notification to corrosion specialist would be implemented to assess the situation and recommend further actions, if necessary.

6.6 A third example involves a small increase in the pH of the feed stream, increasing the corrosion rates above those on which the inspection plan was established. The probability of 2 is assigned. The consequence involves a small leak above reportable quantities so a consequence of B is assigned. Using Figure 4 an IIL is recommended. Action required by operations is to notify the unit inspector and/or designated SME for review and potential modification of the inspection plans.



Probability	A	B	C	D	E
5	🟧	🟧	🟧	🟥	🟥
4	🟨	🟨	🟧	🟧	🟥
3	🟩	🟩	🟨	🟧	🟥
2	🟩	🟩	🟨	🟨	🟧
1	🟩	🟩	🟨	🟨	🟧

Figure 3—Generic Risk Matrix for Assessing IOW levels

7 Examples of IOW's

7.1 An example of an IOW set for high temperature hydrogen attack (HTHA) is shown in Figure 5 Note that mechanical design limits from the construction code for the vessel are outside the IOW limits for the process, which are typically set from some function of the appropriate Nelson curves in API 941. Note also that although the start-of-run conditions (SOR) are within the IOW, the end-of-run conditions may be outside the IOW depending upon hydrogen partial pressure and the duration of the EOR conditions. In this specific case, some owner-users may decide that a short term operation at EOR conditions above the Nelson curve is acceptable based on the amount of time it takes for incipient HTHA to occur, i.e. no significant HTHA damage will occur. Other operators may decide that the IOW should never be exceeded even with EOR conditions. Such decisions and determination of the required risk controls (e.g. the required frequency and extent of HTHA inspections) can be made using appropriate risk analysis and the input of knowledgeable corrosion/materials SME's who are aware of the damage accumulation and incipient attack issues with HTHA.

7.2 Figure 6 outlines how informational, standard and critical IOW limits/targets might interact with different levels of communications (notifications, alerts, and alarms) for controlling elevated temperatures on fired heater tubes.

7.2.1 Several high temperature damage mechanisms are possible in fired heater tubes. In general, long term creep and corrosion from a temperature dependent mechanism are the primary concerns. However, when operating at

Risk	**Type of IOW**	**IOW Guidance/Action**
High	**Critical**	IOW's Required - Limits and durations established on all IOW process parameters for monitoring; IOW's are alarmed/alerted and SME's are notified of exceedances; Operations take urgent predetermined action to return process to normal operation.
Medium High	**Critical or Standard**	IOW's Required - Limits and durations established on all IOW process parameters for monitoring; IOW's are alarmed/alerted and SME's are notified of exceedances; Operations take predetermined action to return process to normal operation.
Medium	**Standard or Informational**	IIL's Identified - IOW's identified suggested limits specified for each IOW; Operations and SME's are alerted/notified of exceedances; Troubleshooting initiated with planned adjustments to operations, inspection/maintenance developed.
Low	**Informational**	IIL's Suggested - Normal operating parameters identified for analysis; Parameters tracked and trended by SME to determine long-term effects on equipment reliability.

Figure 4—Example Risk Chart for IOW Types/Actions/Guidance

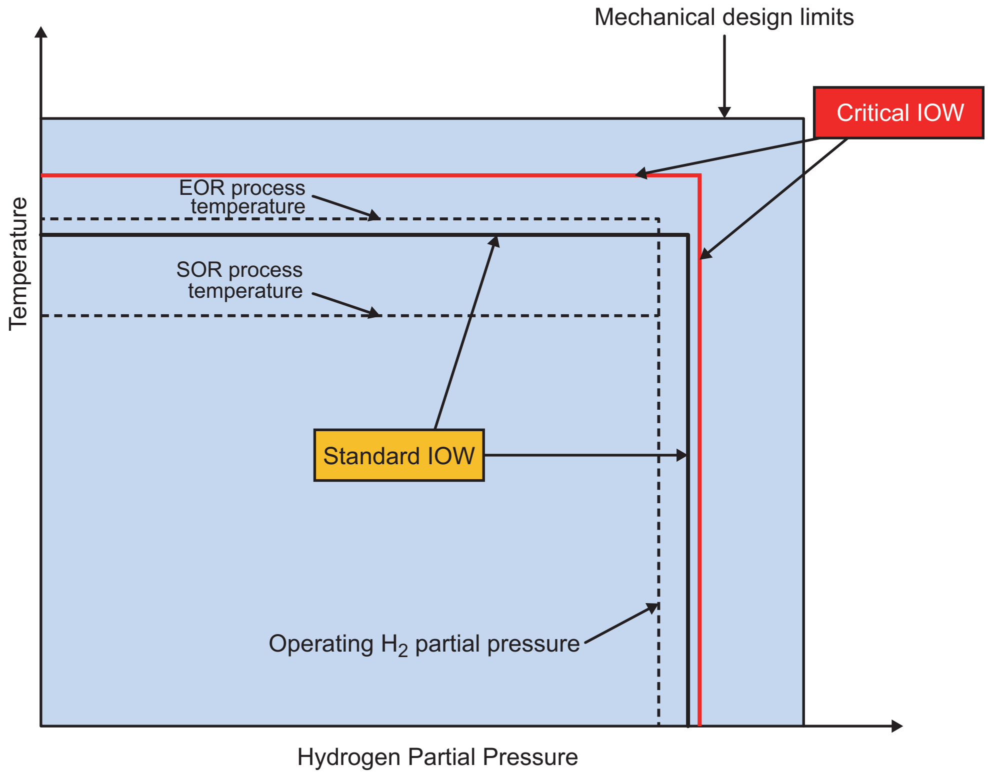
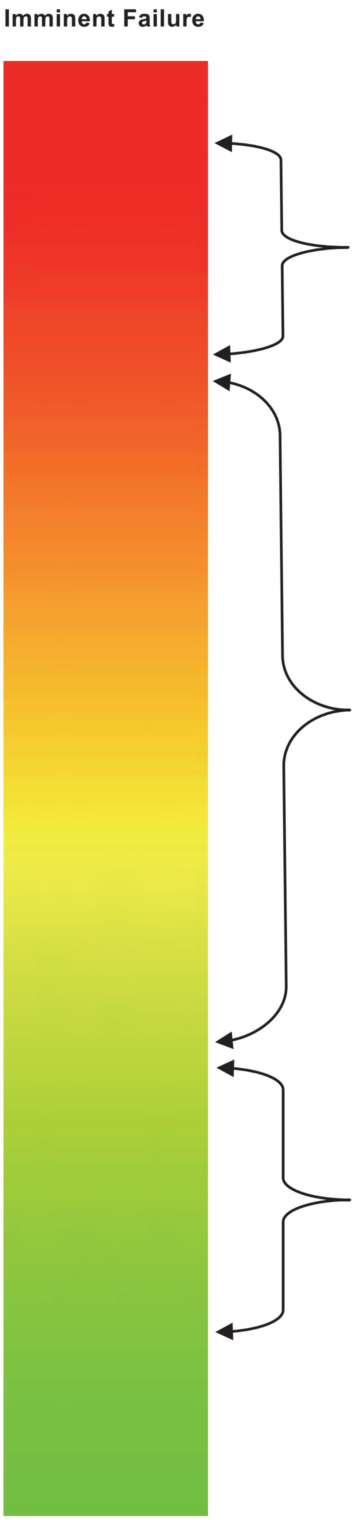


Figure 5—Example of IOW Limits for HTHA in a Hydroprocess Unit



IOW	Potential Issue	Example Response to Exceedances
Typical Range for *Critical* IOW's, Based on Short Term Failure	Short term overheating and stress rupture due to significant reduction in tensile strength	Alarm is set for the Board Operator whom responds immediately with predetermined actions to gain control of the operation or shut down the fired heater
Typical Range for *Standard* IOW's, Based on Remaining Life Assessment	Temperature range for operation where some damage mechanisms may begin to shorten the equipment life, such as creep, sulfidation, oxidation, carburization, etc.	Alarms and/or Alerts are set for Operations which may or may not have a predetermined action and timing to implement. Regardless the situation may be reviewed with SME's and a plan developed to bring the operation back into control and/or adjust the inspection plan and conduct remaining life calculations as appropriate
Typical Range for *Informational* IOW's Based on Design Life	Long term reliability of equipment up to the design life. Typically the SME would be responsible for tracking and trending this information and adjusting the inspection and test plans, as necessary	The SME (e.g. Corrosion/Materials Engineer) is typically responsible for tracking the fired heater tube temperatures and recommending inspection and testing activities such as routine IR examinations, tube strapping, UT measurements, etc.

Figure 6—Examples of Different Types of IOW's for Fired Heater Tubes

temperatures significantly higher than the design, failure by stress rupture can occur rapidly due to overpressure from the significant loss in material strength, i.e. short-term overheat and stress rupture. Per our previous example, heater tubes that have an API 530, 100,000 hour design temperature of 950 °F (510 °C) would have an increasingly shortened service life if operated above this design temperature. A more specific example of how IOW's may be employed is presented in the following sections on how to establish fired heater tube temperature limits to avoid premature rupture or unplanned replacement of the tubes.

7.2.1.1 Informational IOW's Inspection, Corrosion, and Process Engineering personnel (SME's) would be responsible for tracking and trending fired heater tube temperatures operating below the design temperature, <950 °F (510 °C). A tube wall temperature upper limit may be set and/or notifications sent to inform the SME if the temperatures exceed an upper limit of 900 °F (482 °C).

7.2.1.2 Standard IOW Limit The initial standard limit for fired heater tubes that operate in the creep range is frequently set at the API 530 design metal temperature (100,000 hour design life). This standard limit may be adjusted based on an engineering analysis from detailed knowledge of the time dependent damage mechanisms (creep and corrosion), and the estimated remaining life. For this example the standard limit is set at 950 °F (510 °C). An alert (or an alarm) is used to notify SME's and operations when this temperature is exceeded. Operators would be directed to adjust fired heater controls to get the tube temperature back to below 950 °F (510 °C) within a preset amount of time.

7.2.1.3 Critical IOW Limit The critical limit is set at a temperature prior to the point when failure is imminent due to significant reduction in of strength with some amount of safety factor. For this example, a critical temperature limit of 1150 °F (621 °C) was selected. An alarm point is set for the board operator that alarms when this temperature is exceeded and the operator is directed to take immediate actions to regain control or even shut down the fired heater to avoid failure.

7.2.1.4 This example shows how there may be more than one IOW limit for the same process parameter (in this case fired heater tube temperature), for tracking/trending or to gain control prior to reaching a critical IOW limit. In addition, there may be more than one predefined response, depending upon the degree of exceedance of the process parameter limit. In this example, all three levels of IOW's were set to show a progression of failure risk and commensurate communication and response activity initiating with the SME's, then operations and ultimately the board operator to correct the increasing temperature.

7.3 The following are some examples of where critical IOW limits may be appropriate.

- Delayed coker heater pass flows:
  - low flow can contribute to coking and overheating.
- Boiler feed water level:
  - loss of boiler feed water level could quickly cause boiler tube rupture.
- Hydroprocess reactor temperature:
  - metal temperatures below the minimum allowable temperature (MAT) could give rise to brittle fracture.
- Heater tube skin temperature:
  - tube could rupture quickly if overheated, caused, for example, by a no flow or hot spot condition.
- Sulfuric acid strength in alkylation:
  - too low acid strength could cause runaway reaction.

- System pressure on a major piece of pressure equipment:
  - over-pressure could result in major environmental and/or community impact.

7.4 The following are some examples of where standard IOW limits may be appropriate.

- Hydrocracker reactor effluent air cooler (REAC) NH_4HS concentration:
  - corrosion of the air cooler and downstream piping.
- Heater tube skin temperature:
  - metallurgical creep could lead to eventual tube failure.
- Crude fractionator dew point temperature:
  - sustained operation below dew point could cause damage to fractionator internals or potential loss of containment.
- pH of crude tower overhead:
  - sustained operation below standard pH level could lead to corrosion of heat exchanger components, especially tubing and piping and potential loss of containment.
- Hydroprocess units:
  - water and/or chloride carry-over in hydrocarbon feed streams or hydrogen could cause accelerated corrosion from ammonium salts and hydrogen chloride solutions.
- Desalter outlet conditions:
  - sustained operation with salt content above standard level could lead to corrosion and potential loss of containment.
- Crude desalter temperature:
  - temperatures higher than 300 °F will cause permanent damage to the Polytetrafluoroethylene (PTFE) bushings that insulate the electric grids, deterioration of these bushings will cause grid shorting and rendering the desalter non effective.
- Sulfuric acid alkylation deisobutanizer acid wash:
  - acid circulation rate – high flow will increase acid entrainment due to over mixing, low rate will not allow for sufficient contact between acid and hydrocarbon.
- Sulfuric acid alkylation – iron content in fresh purchased acid:
  - fresh acid will dissolve iron to achieve saturation point.
- Delayed coker feed TAN content:
  - high total acid number (TAN) can cause corrosion in the temperature range of 425 °F to 750 °F.
- Delayed coker feed sodium content:
  - sodium will cause rapid fouling of the heaters and can cause over heating of tubes;
  - solids content, coupled with a critical flow rate, can result in erosion/corrosion.

- FCCU fractionator bottoms system:
  - solids content coupled with a critical flow rate, can result in rapid erosion/corrosion.

7.5 The following are some examples of where IOW informational limits (IIL's) may be appropriate.

- Calculated heat transfer coefficients and pressure drops for heat exchangers.
- Calculated dew points to avoid water drop out.
- Calculated salt deposition temperature to avoid precipitation of salts and fouling.
- Calculated wash water vaporization rates for wash water effectiveness.
- pH, chlorides, hardness, iron, cyanides in wash water to avoid corrosion.
- Temperature differences between parallel banks or tubes from infrared surveys for flow distribution in reactor effluent air cooler (REAC) systems that could lead to accelerated corrosion.
- Ammonia content in a crude overhead system that could be assessed to determine if ammonium chloride fouling and corrosion may be occurring.
- Carbonate content in the FCCU gas plant and claus quench tower waters that would promote carbonate stress corrosion cracking.
- Process though-puts that exceed design and may affect damage mechanisms.
- Turbidity of cooling tower water—increase can be an indication of increased risk of deposits and biological attack.
- Cyanide content in FCCU and DCU gas plant waters. The presence of cyanide will promote wet H_2S cracking and promote general corrosion by destroying the protective iron sulfide layer.
- Iron concentration (ppm) in the steam condensate system.
- Iron will indicate accelerated corrosion due to low pH condensate. This could be an indication of upstream problems in either water treatment or neutralizing amine injection.
- Organic chlorides in purchased NHT feeds in a sampled tank that is not yet on line. Organic chlorides can lead to very high corrosion rates in the NHT and other hydroprocess units.
- Temperature that has increased as a result of process creep. The temperature may have increased to a point that it now puts the equipment in the sulfidation range.
- Temperature that has fallen into the external stress corrosion cracking range on an insulated stainless steel vessel.

7.6 More detailed, specific examples of IOW's for a few generic process units are included in Annex A. A suggested tabular recording of IOW's is shown in Annex B, including the IOW parameter, the related damage mechanisms, the required response, the timing of the response, related information and responsible party. An example IOW work process for a hypothetical exchanger is shown in Annex C.

8 IOW Development

8.1 A written procedure should document the IOW work process. It should contain the following elements:

- implemented by a multidisciplinary team of SME's;
- roles, responsibilities, and qualifications for team members;
- required data and information to be reviewed;
- depth of design and operating analysis;
- integration with existing PSM and operational programs;
- how the IOW's are to be implemented;
- how the IOW's will be documented;
- handling of suggested monitoring instrumentation/controls and/or sampling points;
- the frequency of subsequent IOW reviews and to whom ownership of the procedure belongs;
- how IOW exceedances will be communicated and to whom; and
- any required follow up, e.g. modify inspection plans or investigation of exceedances.

8.2 In order to develop the necessary information, identify potential damage mechanisms and failure scenarios along with consideration for future operating conditions and business objectives, the combined efforts of a multi-disciplinary team of SME's is recommended. Typically this team would consist of:

- site corrosion engineer/specialist;
- unit process engineer/technology specialists;
- unit inspector;
- unit pressure equipment engineer;
- experienced unit operations representative(s);
- process chemical treatment vendor (as needed, ad hoc); and a
- facilitator knowledgeable in the IOW work process.

8.3 The qualifications of the team and the quality of the development process and therefore the quality of the IOW's produced is dependent upon collaborative effort from the interaction of this group of knowledgeable, experienced SME's.

8.4 Considerable information is needed by the SME's on the IOW team in order to do a comprehensive job of constructing each unit specific set of IOW's. In order to facilitate the effectiveness and efficiency of the IOW work process, this information should be collected and brought to the IOW team meeting to the extent possible. This information typically could include:

- process and reactive chemistry knowledge;

- process flow diagrams to systematically review the process during IOW team meetings;
- P&ID's that show sample points, IOW monitoring instruments, etc.;
- piping isometric drawings that show all injection points, mix points, deadlegs and other piping hardware details that are included in the inspection program;
- existing operating windows and defined actions that are already in effect;
- identification of startup lines, temporary use lines and normally closed valves;
- operating and maintenance procedures;
- process chemical treatment programs;
- feed sources, volumes, and compositions including intermediate products;
- knowledge of damage mechanisms, possible and probable that could occur in the process unit;
- historical operating, maintenance and inspection records for the process unit;
- failure analysis and lessons learned reports for the operating unit and/or similar operating units;
- equipment/process design data; laboratory data; operating data for the process unit (note the emphasis on data rather than "impressions" or SME judgment);
- start-up, shut-down, and unusual operating conditions;
- MOC records for the operating unit;
- existing sample points and sample data;
- existing process variable controls and measurement points e.g. pressure indicators (PI's), temperature indicators (TI's), analyzers, flow controllers (FC's), etc.;
- metallurgical and corrosion information and data, (published and company private) related to the damage mechanisms anticipated for the process unit;
- materials of construction and materials engineering knowledge, including CMD's;
- operating knowledge;
- applicable industry and company recommended practices and standards;
- process and corrosion modeling tools;
- original unit feed composition.

8.5 Examples of unit specific process data that can be used during the IOW process include the following.

- *Crude units*—Historical crude assays, average sulfur composition for the raw feed and primary cuts or product streams, total acid numbers, fired heater monitoring data (IR and process temperatures), side-stream temperatures, overhead process parameters such as velocities, pH, choride contents, crude salt content, desalter efficiency and reliability, caustic injection rate (and strength) into desalted crude etc.

— *Hydroprocessing Units*—Hydrogen, hydrogen sulfide and ammonia partial pressures, wash water volumes, injection points, and sources and quality of water, etc.

— *Amine systems*—Type of amine, loading, filtration, overhead bleed/purge rates, chloride content, HSAS content, % water in amine, steam temperature of amine reboilers, etc.

— *Catalytic Crackers*—Polysulfide injection systems, slurry solid content, HCN and carbonate concentration in Gas Plant System, etc.

— *Claus Sulfur Units*—Acid gas feed temperature, temperature of cold wall thermal reactor, temperature of final condenser outlet temperature, acid gas loading, sulfur levels.

— *Sour Water Strippers*—Concentration of NH_3 in Circulating Reflux.

— *Merox Units*—Sodium content of DSO, air controls.

— *Selective Hydrogenation Unit*—Di-Olefins content.

— *Sulfuric Acid Alkylation*—Spent acid strength to storage, acid strength, acid temperature, water content of acid, acid/hydrocarbon ratio in contactors, contactor Isobutane/Olefin ration, acid precipitator amps & voltage, acid circulation rate to DIB feed acid wash, DIB acid wash mix valve pressure differential, caustic strength of Alky DIB caustic wash.

— *Hydrofluoric Acid Alkylation*—Water content in acid, isostripper and depropanizer temperatures, defluorinator breakthrough monitoring.

— *Catalytic Reformer*—Fired heater temperatures, H_2S content of reformer recycle gas, Water content of recycle gas, HCl content of hydrogen exiting the hydrogen HCl scrubbers.

— *Delayed Coking Unit*—Sodium in feed, TAN, velocity in coker heaters.

9 General Considerations for Establishing IOW's and Their Limits

9.1 Historical integrity and reliability problems as well as changes that are anticipated in the process unit should be considered in the IOW development.

9.2 There may be upper and lower limits that need to be established and there may be one or more levels of those limits with different actions within different time frames required as each IOW level is exceeded. It will be up to the IOW team to determine whether each IOW needs to have both upper and lower limits, and if standard and/or critical limits need to be established for each IOW. Not all IOW's will have critical limits, and many may have only an upper or a lower limit. Some critical or standard limits may warrant having IIL's established.

9.3 Actual operation sometimes deviates from design for various reasons. Those differences can cause accelerated or unanticipated degradation with undesirable consequences. Those deviations must be considered.

9.4 There are numerous documented cases within the industry of accelerated corrosion and cracking under adverse conditions that range up to a few inches per year (see Table 1 for examples). The materials/corrosion specialist needs to be aware of this type of information to help the team decide what the appropriate response needs to be and how fast the actions need to be implemented.

9.5 Numerous issues can cause deviations between actual and design operating conditions, including fouling of exchangers in series, operating with exchanger by-passes open, process conditions creeping upward without notice, lack of understanding of the nature and consequences of unanticipated degradation, misunderstanding between

Table 1—Examples of Accelerated Corrosion Rates That Can Occur Under Some Circumstances

Unit: Corrosion/Damage Mechanism	Documented Out-of-Control Corrosion Rates	Time to Failure
Crude Unit: HCl/Amine Chloride Corrosion in Ovhd and TPA	>2000 mpy	Failed a new exchanger bundle in 18 days.
Reformer: HCl/Ammonium Chloride	>3500 mpy	New alloy finfan exchanger failure in 3 months, related to over injection of PERC and low operating temperatures.
Catacarb Unit: Wet CO_2	>5000 mpy	Failure can occur in days to weeks on the piping at a dew point.
FCC Unit: Erosion of slurry system piping	>1000 mpy	Multiple failures in slurry pumps and piping within 6 weeks after suspected cyclone failure.
Alkylation: H_2SO_4/Acid Esters	>15,000 mpy	Failure occurred in 11 days on a new pipe reducing elbow where H_2SO_4 was diluted with H_2O + Cl.
HDS; HCl/Ammonium Chloride	>300 mpy	Failure occurred at a piping mix point combining H_2+Cl and wet HDS H_2 in approximately 2 years.

construction code design conditions and material of construction design limits for specific types of degradation, and not recognizing the impact of end-of-run (EOR) conditions versus normal or start-of-run (SOR) conditions.

9.5.1 For example, if there are banks of heat exchangers in series in high temperature, high pressure hydroprocess service, designers sometimes assume operating conditions over the life of the plant based on the maximum expected degree of fouling. However, if the inlet exchanger in the series fouls more than expected and no longer cools the hydroprocess stream sufficiently, the next exchanger(s) in the series might see higher temperatures than it was designed for, in which case it might become susceptible to HTHA, sulfidation or low temperature damage mechanisms like ammonium chloride corrosion, for which the materials of construction in the downstream bank may not be designed to handle. Another situation occurs when process conditions begin to creep upward or downward over time; also known as “process creep”. This might entail scenarios such as periodic, but small increases in temperature, small increases in hydrogen sulfide content, increases in unit throughput or increases in hydrogen partial pressure. Another example of process creep is the incremental unit through-put over time that eventually exceeds design conditions and can result in accelerated erosion-corrosion. If those changes are not noticed, or not put through a management of change process, or if the proper IOW’s were not in place, then unanticipated and therefore undetected materials degradation could occur.

If for some process reason, operators open a by-pass around an upstream exchanger causing hotter hydroprocess material to enter downstream equipment that was not designed for those hotter conditions, then again unanticipated and undetected materials degradation could occur, as for instance HTHA or sulfidation.

9.5.2 A very specific set of operating instructions may be needed to address situations such as shock chilling or auto-refrigeration where preventing potential brittle fracture will be the primary concern of operations. In such cases, it may not be appropriate to simply return the process to normal operating conditions e.g. repressurizing, without due attention to the potential for avoiding brittle fracture.

9.5.3 In some hydroprocess equipment, EOR conditions (e.g. temperature and hydrogen pp) are more severe than SOR or normal operating conditions. If actual EOR operating conditions were more severe and/or lasted much longer than original design or normal operating conditions, that could result in exceeding the HTHA resistance of the materials of construction.

9.6 The number of IOW’s for each process unit will depend on the:

- number and extent of damage mechanisms anticipated and likely to be present;
- risks associated with the process fluids;
- complexity of the process unit;
- extent of corrosion resistant materials of construction.

9.7 The numbers of IOW’s for a typical process unit might range from 20 to 60 depending upon the above issues. These would be in addition to other operating windows that may affect process unit control and product quality, but have nothing to do with equipment integrity. Except for the least complex and least corrosive process units, if there are a relatively low number of IOWs identified for a particular process unit, some important process variables may not be captured in the IOW list.

9.8 The result of analyzing all this information and the team deliberations is typically a set of reasonable, practical IOW’s that are not too conservative and not non-conservative, both extremes of which are not desirable and need to be avoided. Nonconservative IOW’s could lead to more degradation than desirable or anticipated and therefore higher risk; whereas IOW’s that are too conservative could lead to a waste of valuable resources and lost opportunity. For example, establishing a fired heater tube-skin temperature limit that is too high may not allow the operator enough time to adjust firing conditions before tube damage occurs; whereas, setting a tube-skin temperature too low may lead to limiting fired heater operating conditions [and therefore lost profit opportunity (LPO)], where it is unnecessary to do so from a materials engineering standpoint.

9.9 Only a small percentage of IOW's e.g. five to ten percent of the total may end up being designated by the team as “critical limits” i.e. where the operator will need to take immediate/rapid action to control the process or shut down. Most of the remaining IOW's will typically be designated as “standard limits” i.e. where the operator needs to take action within a specified timeframe to get the process back within the IOW limits in order to avoid escalation of the issue to a critical limit. A smaller subset may be designated as IIL's i.e. where SME's will need to be notified for potential follow up actions.

9.10 Exceedances of critical IOW limits may have more formal communications and follow up requirements and more extensive reporting to stakeholders and be treated similar to an incident investigation, whereas, standard limit and IIL exceedances may require reporting only to technical and inspection personnel for follow up and investigation. If systems are available, automated communication of IOW exceedances from on-line control and information systems directly to designated stakeholders can improve the effectiveness and efficiency of the IOW communication process.

10 Documenting, Implementing, and Training on Established IOW’s

10.1 Effective implementation of the IOW list is equally as important as establishing IOW’s, so that effective actions within a specified timeframe are taken each time an exceedance occurs. The process for implementing IOW’s should be integrated with that for other operating variables. IOW’s requiring operator actions are most should be included in standard operating procedures. A comprehensive list of IOW’s should be readily available and communicated to responsible personnel, which could typically include:

- operations personnel,
- operations supervision/management,
- business/oil movements,
- inspection personnel,

- process engineers,
- reliability engineers,
- corrosion/materials specialists,
- safety/PSM/environmental personnel.

10.2 There can be several methods to document each set of IOW's. Two examples are shown below, one being more detailed (and thereby more useful from a broader perspective) and another being a simpler, more concise (but less useful from a broader perspective).

10.2.1 *A More Concise Method*—Simply compile a list of IOW's for each process unit and include in the standard operating procedures, including:

- the specific limits established,
- the recommended operator intervention/control steps,
- the timeliness of each intervention/control action, and
- required IOW exceedance communications

10.2.2 *A More Detailed Method*—Include the IOW's as part of a comprehensive document on corrosion control in every process unit and add the IOW's and response requirements to standard operating procedures. These documents have been called corrosion control documents (CCD's), corrosion control manuals (CCM's), or risk-based inspection (RBI) data files by some in the industry. These documents may include, but are not limited to the following.

- Description of the process unit and the normal process conditions.
- Shutdown, start up, and abnormal operating conditions that may affect corrosion and other damage mechanisms, including the possibility of inadvertent contamination of process streams with unexpected but possibly predictable corrosive species.
- Process flow diagrams (PFD's) showing all construction materials.
- Corrosion loop diagrams (CLD's) which are areas of similar corrosion mechanisms, similar operating conditions, and similar materials of construction in each portion of the unit.
- Probable damage mechanisms in each corrosion circuit, where each damage mechanism is expected to occur, the relative susceptibility to the damage mechanisms, as well as likely damage rates expected to occur and under what circumstances.
- A history of corrosion problems that have been experienced in this process unit or similar units.
- Quantitative and predictive models for the damage mechanisms.
- Corrosion control procedures and practices such as those dealing with chemical injection, inhibitors, water washing, neutralizers etc.
- Recommended types of inspections focused on specific damage mechanisms, corrosion monitoring, process parameter monitoring process changes, construction materials, etc., basis for each IOW, including any assumptions made.
- Risk analysis performed to prioritize the various IOW's and their associated monitoring methods, and of course.

- The applicable IOW's that include the information in the simpler format above for recording IOW's.

The more detailed documentation methods can become a resource for the following.

- The entire corrosion and damage management strategy for the process unit.
- The implementation effort for all IOW's that will be input into the process monitoring and control system.
- Training and reference material for operators, engineers, inspectors and others that need to know the background for why each IOW was established, especially when considering possible changes.
- Risk-based inspection planning.
- Management of change decision-making that may affect equipment integrity, and process hazards analysis (PHA) discussions.

10.3 Various combinations of the above two documentation methods can be developed depending upon the needs and desires of the owner user.

10.4 Like all operating envelopes, an important part of IOW implementation is training. Once IOW's are established, unit personnel need to become knowledgeable about all the unit-specific IOW's in their operating area, and especially knowledgeable in the reasoning behind them, so they can understand why it's so important to take the predetermined action within the specified timeframe. They also need to understand the undesirable consequences of failing to take action within the specified time frame. This operator training should include such things as:

- why the IOW was established, i.e. its purpose and intent;
- what damage mechanism is being prevented or controlled by the limits established;
- a clear understanding of the difference between informational, standard and critical limits, as well as the reason for the different response actions and timing;
- if there are multiple levels of the IOW's, i.e. upper and lower, as well as multiple levels of responses and response timeliness, then the reasons for each level of response needs to be fully understood;
- what can happen in the process unit, both short and long term, if the established responses are not implemented in a timely fashion when limits are exceeded;
- the desired exceedance communications, by what mechanism and with whom to communicate, in the event that an IOW limit is exceeded.

10.5 Training should include describing the difference between mechanical and process design conditions. Those involved in MOC assessments for changes in the process design conditions should have an understanding of the materials selection design conditions. There sometimes is a misunderstanding regarding the differences between the design conditions stamped on the nameplate of the equipment and the actual process operating limits of the equipment based on damage mechanisms. The mechanical design limits for pressure and temperature per ASME Code construction stamped on the vessel may be much higher than the operating limits established for materials of construction degradation resistance. This difference is one of the many reasons that IOW's are beneficial.

11 Monitoring and Measuring IOW Parameters

11.1 To monitor and measure IOW parameters, as well as other operating envelopes, control systems and procedures are necessary to store the IOW's and notify the operator when an exceedance has occurred. That will likely involve additional monitoring and control instruments and/or sampling points for some IOW variables. If it's a monitoring instrument, then instrumented displays and some alarms will likely be needed. If it's a sample point, then procedures and practices will be needed to analyze a designated process stream and report it back to the operator within a predetermined amount of time so that the appropriate actions can be taken in the event of an IOW exceedance. Some systems generate trending data for IOW's and automatic electronic notifications to a predetermined list of stakeholders.

11.2 The overall response time of the system needs to be considered when setting alarm, and "notification" limits/ levels. The response time needs to account for not only the limitations on the instrument/detector response but also the overall design and limits of the communication system (getting the message to the intended audience). System response time is the length of time from when a limit has been violated until the mitigation procedure is activated. This time will be a function of system deployment, device response time, and activation strategy. System response time should be scaled relative to the risk level for critical and standard IOW's. The physical characteristics of the instrument and detection system also need to be considered. It is important to note that device response time may be significantly affected by ambient conditions. See API 556*,* for practices on control overrides, alarms, and protective functions for fired heaters.

11.3 In most cases, alarms will normally accompany all critical IOW's and some standard IOW's, depending upon necessary timing of IOW response. Process safety management may need to review the total number of alarms to avoid situations involving "alarm flood" in the event of an emergency. Notifications to specified stakeholders/SME's should accompany critical and selected/specified standard and informational IOW's.

11.4 Sample points may be an interim process monitoring application where more data is needed to understand the process parameter and refine required frequency of measurement or sampling in order to justify the installation of future control or measurement instrumentation.

11.5 For some IIL's, several types of corrosion monitoring methods may be used, including: corrosion coupons, corrosion and hydrogen probes, and infrared thermography.

11.6 Appropriate monitoring equipment should be specified and installed at strategic locations to provide the information necessary to determine if an IOW exceedance may be occurring.

11.7 Typically an agreed upon list of IOW's will involve capital investment for monitoring and sampling systems and/ or increased workload for laboratory analysis. This is because adequate monitoring and control systems may not be in place for each necessary IOW that has been established. Risk analysis and risk ranking is useful for prioritizing those investments and comparing them to all other capital and expense needs of the plant.

12 Updating IOW's

12.1 Periodic team meetings between Operations and SME's may be useful to monitor the status and update the IOW list, i.e. reassessment of the IOW list. This should include a periodic review and update of the potential damage mechanisms. The damage mechanism review may be integrated with the periodic review of an RBI analysis, where it has been implemented.

12.2 The IOW list should be updated as needed to account for process and hardware changes (recent and planned), exceedance feedback, inspection results, new information about damage mechanisms, or a variable or damage mechanism identified after the original IOW list was established.

12.3 The MOC process should be applied whenever critical or standard IOW variables are being revised or updated, utilizing the same types of experienced SME's that were used to generate the original IOW list. A modified, streamlined MOC process specifically addressing IOW updates could be developed by owner-users.

13 Roles, Responsibilities, and Accountabilities for IOW's

13.1 Numerous personnel at the plant site have roles and responsibilities for IOW creation, implementation, and maintenance including those in:

- inspection,
- corrosion/materials,
- operations,
- process engineering/technology,
- plant management,
- process safety management,
- laboratory,
- control systems,
- mechanical and/or reliability engineers.

13.2 Inspection personnel have a role bringing data to the IOW team for creating and updating IOW's, as well as adjusting inspection activities/plans as necessary when IOW exceedances are reported to them.

13.3 Corrosion/materials specialists have a role to identify damage mechanisms for the IOW team. A corrosion/materials specialist should also supply the CLD's/CMD's (where they are available), and estimated corrosion rates where measured rates for the current operating conditions are not available. They also have a role in understanding exceedances and advising inspection personnel on how inspection activities might need to be revised to account for the exceedance, if any, as well as advising process engineers on process issues that may need to be considered to avoid long term materials degradation issues. A corrosion/materials specialist will often have the role and responsibility of facilitating the IOW team, as well as documenting and distributing the results of the IOW work process. The corrosion/materials specialist may also have a role in providing operator training on IOW's.

13.4 Operations is responsible for monitoring and responding to any IOW exceedances in the manner designated in the IOW control system and documentation. In addition they provide information to the IOW team about current operating practices and data. They will also provide information about the frequency of upset conditions. This would include obtaining water and process samples which have been identified as IOW monitoring points. Additionally operations have the responsibility to communicate any IOW exceedances in the designated manner to other designated stakeholders for their potential actions.

13.5 The unit process engineer has the role of bringing process design and engineering data to the IOW team. Often the unit process engineer is the designated "owner" of the IOW list and responsible to ensure that all IOW's are properly and continuously implemented in the manner designated in the IOW documentation. The owner of the IOW work process would also have the responsibility to ensure that exceedances were properly reported to others and a role in responding to exceedances and ensuring that responses to exceedances were handled and implemented in a timely manner.

13.6 Plant management has the role and accountability of ensuring that the IOW work process is adequately staffed with knowledgeable, experienced SME's; that the work process is carried out in a timely manner; that all IOW's agreed upon are implemented in a timely manner; and that adequate resources for monitoring, sampling, and control systems are designed, purchased, installed, and implemented. Plant management would also have the responsibility to audit the IOW work process to ensure that it is operating in accordance with specification. Operations management would have the responsibility to ensure that all unit operators are adequately trained on IOW's and their required responses to exceedances.

13.7 PSM personnel have a role and the responsibility for ensuring that the IOW work process is adequate to meet the process safety information (PSI) aspect of local and federal regulations, as well as ensuring that the MOC process is properly utilized for making changes to the IOW list.

13.8 Laboratory personnel have a role in implementing, recording and reporting any required sample analyses used for IOW monitoring in a timely manner, per the IOW documentation.

13.9 Control systems personnel would have a role and the responsibility for designing, purchasing, installing and maintaining any control and monitoring systems for IOW's.

13.10 Mechanical and/or reliability engineers also have a role in identifying previous equipment failures and experiences.

13.11 The IOW team facilitator is often best accomplished by an experienced corrosion/materials or mechanical integrity specialist, either from the plant, a central office, or a third party. One of the facilitator's roles should be oriented toward eliciting information about what is actually happening in the field relative to what is in the documented records or what is "thought to be happening" by those who are not operators. The facilitator needs to have the skill for asking the right probing questions in order to fully understand issues that may impact the IOW work process.

13.12 A good working knowledge of industry failure frequencies is also desirable for the facilitator or someone else on the team.

14 Integrating IOW's with Other Related Work Processes

14.1 The IOW work process should be closely integrated with pressure equipment integrity (PEI) work processes (inspection, corrosion management and maintenance) at the plant site. As indicated in the introduction, the pressure equipment integrity work process can only be adequately accomplished when both work processes (PEI and IOW) are performing effectively with close interaction between the two work processes.

14.2 The IOW list and documentation should be a resource for PHA. IOW exceedances especially critical IOW exceedances should be reviewed by the PHA team (or as pre-work by the IOW team) to determine if actions or limits may need to be revised.

14.3 The IOW work process and documentation should also be a resource for the RBI work process, (and vice versa) especially since both require the same level of analysis of potential damage mechanisms. In fact, an IOW workshop and RBI workshop could be combined where there is complete overlap in resources and timing of the two programs. The analysis of IOW exceedances may affect the inspection plans generated by RBI, or any other modes of inspection planning, including time-based and condition-based inspection plans. The information assembled to produce the more detailed IOW documentation mentioned in 10.4 can become part of the front end data input to the RBI process, which would in turn produce a detailed risk-based inspection plan for each piece of fixed equipment including: inspection scope, methods, techniques, coverage, frequency, etc. Refer to API RP 580 and RP 581 for additional guidance on the RBI work process. API 580 is the generic boundary document detailing everything that needs to be included in an effective and complete RBI work process; while API 581 is a specific step-by-step work process for doing RBI which includes all the elements of API 580.

14.4 As indicated in sections 1.3, 5.7, 8.4, 10.5, 12.3 and 13.7 the MOC work process must be closely integrated with the IOW work process for any changes, additions or deletions to be made to the IOW list.

Annex A
(informative)

Examples of Potential Process Parameter's for IOW's for Generic Process Units

The following is an example list of a few parameters for potential IOW's for a generic amine process unit:

- amine concentration;
- water content;
- rich amine acid gas loading;
- lean amine acid gas loading;
- regenerator steam to feed ratio;
- velocity in rich amine piping;
- reboiler steam temperature;
- lean amine temperature from the bottom of the regenerator;
- heat stable salt (HSS) concentration;
- iron content in circulating amine;
- sour water velocity from regen O/H condenser to reflux drum;
- amount of reflux being purged (% vol);
- NH_4HS and CN levels in the overhead;
- temperature of acid gas piping to SRU;
- total suspended solids.

The following is an example list of a few parameters for potential IOW's for a generic crude distillation unit:

- crude fired heater tube skin temperature limits;
- crude fired heater outlet temperature, minimum pass flow and stack temperature;
- TAN limits on crude feed and cuts;
- pressure drop across fired heater coils;
- salt/chloride content in feed streams;
- inlet/outlet temperatures in feed preheat exchangers;
- sediment content of feed streams and desalted crude;

— water content of feed and various process steams;

— desalter wash water rate;

— pH, O_2 and NH_3 contents of desalter water;

— desalter efficiency, operating temperature and outlet salt content;

— hydrolysable and organic chloride limits downstream of desalter;

— caustic injection rate in the desalted crude;

— various distillation column top temperatures;

— overhead wash water rate;

— filming and neutralizing amine injection rates;

— pH in water boots;

— iron, sulfates, chlorides, ammonia, tramp amine, and hardness in overhead water boots;

— tramp amines in straight run naphtha and kerosene;

— oxygen ingress in vacuum systems;

— inlet/outlet temperatures for specific exchangers.

The following is an example list of a few parameters for potential IOW's for a generic hydroprocess unit:

— TAN, nitrogen, chlorides, fluorides, sulfur and water contents of feed streams;

— water content at outlet of coalesce;

— HCL content of hydrogen makeup;

— chloride content of feed;

— inlet/outlet temperatures for specific exchangers;

— tube skin temperatures, stack temperature and minimum pass flow rates for hydroprocess heaters;

— hydrogen purity;

— reactor bed temperatures and pressure drops;

— wash water flow rates;

— cold separator sour water NH_4HS and Chloride contents;

— O_2, iron, ammonia, chloride and calcium in injected wash water;

— NH_4HS content;

— hydrogen sulfide content in effluent, recycle gas and high pressure separator overheads;

- water carryover into fractionation and side strippers;
- fractionation overhead chemical injection rates and carrier flow rates;
- fractionation overhead sour water NH_4HS and chloride contents;
- maximum temperature and pressures for start-up and cool down of reactors.

The following is an example list of a few parameters for potential IOW's for a generic sulfuric acid alkylation process unit:

- water content of feeds and coalescer outlet;
- feed make up oxygenates, sulfur, and non-condensables;
- coalescer water boot pH and temperature;
- water in acid in reaction system and velocities in carbon steel piping;
- reactor temperature and contactor motor amps;
- settler operating pressure;
- effluent exchanger outlet temperature;
- acid precipitator amps and voltage;
- acid loss and polymer production;
- fresh, circulating and spent acid strength;
- temperature and caustic strength in caustic wash system;
- temperature and velocity maximums for carbon steel piping in caustic wash system;
- acid and caustic carry over;
- water boot pH;
- Delta P in some exchangers (salt deposition).

The following is an example list of a few parameters for potential IOW's for a generic steam methane reformer unit:

- feed gas condensate pH;
- H_2S content of feed gas (if refinery gas is used);
- hydrotreater and desulfurizer—temperatures and hydrogen partial pressures;
- fired heater tube temperatures;
- heater steam to carbon ratio;
- temperature of syngas to low temperature shift reactor and PSA;

- chloride and ammonia (e.g. brass tubes present) content of process condensate;
- corrosion inhibitor limits in hot potassium carbonate solutions.

The following is an example list of a few parameters for potential IOW's for a generic fluid cat cracker unit:

- catalyst hopper temperature;
- expansion joint maximum temperatures;
- fractionator bottoms slurry content, temperature and sulfur content;
- volumetric flow for cyclone underflows;
- Delta P for slurry pump suction strainer;
- gas oil temperatures and sulfur maximums;
- fractionator overhead top temperature;
- fractionator wash water and polysulfide rates;
- fractionator overhead pH, ammonium bisulfide, sulfides, carbonates and chloride content;
- wash water rate for wet gas compressor interstage condenser;
- wet gas compressor interstage separator boot pH, sulfides, ammonium bisulfides, chlorides, and cyanides.

The following is an example list of a few parameters for potential IOW's for a generic delayed coking process unit:

- TAN, total sulfur and sodium of Coker feed;
- coker fired heater tube-skin temperatures;
- pressure drop across fired heater coils;
- rate of velocity steam Injection or process flow rate through radiant coils;
- rate of water injection in fractionator overhead, compressor interstage, and compressor final stage;
- ammonium polysulfide activity in injected water;
- ammonia, iron, cyanide, carbonate, chloride, pH in water from fractionator overhead accumulator and compressor discharge receivers. Calculate ammonium bisulfide;
- water fraction in stripper bottoms product and rate of water draw off of stripper water separator;
- velocity in sour water piping;
- maximum diffusible hydrogen in the compressor drums and absorber;
- water fraction in debutanizer overhead product and rate of water draw off in debutanizer overhead receiver.

Annex B
(informative)

Sample Format for Recording IOWs

Equipment and/ or Process Stream	Parameter to be Monitored or Controlled	IOW Type and Limit	Comments/Reasons/Actions/Timing	Party(s) Responsible for Monitoring, Control and Response Actions (who does what)
e.g. FCCU feed, fractionator OH, slurry system, reactor, heat exchanger outlet, chemical injection, etc.	e.g. temperature, chlorides, sulfides, water content, cyanides, salts, flow rates, etc.	e.g. Standard max Standard min Critical max Critical min, etc. Informational Target range	e.g. Explain why the parameter is being measured and what can happen if it is exceeded. Explain how the operator needs to respond and how fast. Explain how the parameter is to be measured and how frequently. Explain who is to be notified in the event of an exceedance.	e.g. process engineer, operator, chemical treatment vendor, corrosion specialist, etc.

Annex C
(informative)

Example of an IOW Development for a Heat Exchanger

IOW's are typically developed on a unit basis or for an entire system, but in some cases are associated with a specific equipment item. The following example highlights how an IOW might be formulated for one exchanger.

In this hypothetical example, a crude unit fractionator tower bottoms exchanger (X-1) is potentially under alloyed for future service (sulfidic corrosion concern). Based on the current feed slate to the unit, the actual measured corrosion rate is acceptable, but the refinery is planning to process additional higher sulfur crudes in the near future. This exercise will look at the data development and thought process involved to set appropriate IOW's for this hypothetical exchanger.

Step 1 – Define the Operation

This X-1 exchanger is utilized in the atmospheric gas oil (AGO) stream which receives a steady diet of blended crudes containing 0.30 % sulfur and minimal naphthenic acid. The operating temperature is 600 °F with little to no temperature variation. There is a desire to increase the total sulfur in the AGO in the future from 0.30 up to 0.50 wt% and increase the operating temperature from 600 °F to 650 °F with no increase in TAN. The next full outage that would provide an opportunity to inspect, repair or replace this exchanger is 5 years from the proposed change.

Step 2 – Corrosion/Damage Mechanism Identification

The X-1 exchanger was fabricated from 1-1/4 Cr steel on the shell side (receives an AGO stream) and operates at 600 °F with an estimated 0.30 wt% sulfur (total). The primary damage mechanism of concern currently and for the future operation is sulfidation; naphthenic acid has not been a concern in this Unit. The estimated corrosion rate potential utilizing the Modified McConomy Industry curves is approximately 7.6 mpy (the current measured corrosion rate is only 5 mpy). Differences between the theoretical/potential rate and the measured/observed rate are likely due in part to the amount of reactive sulfur available in the specific Crude slate. For the future operation of 0.50 wt% sulfur and an increase the operating temperature to 650 °F the estimated corrosion rate is 16 mpy. Thus, the metallurgy for this exchanger may be under-designed for the new application.

Step 3 – Determine the parameters that will potentially affect the reliability of this Equipment (Long Term)

- Crude slate/blend.
- Total sulfur at AGO cut.
- Reactive sulfur at AGO cut.
- Total acid number (TAN) at AGO cut.
- Operating temperature (and time if variable) at X-1 shell.
- Velocity of process fluid.

Step 4 – Define the Critical Operating Parameters (measurable and controllable)

Sulfidic corrosion is a co-dependent process that is based on the amount of reactive sulfur present and the temperature for a given material of construction. Sulfidation rates may be accelerated by naphthenic acid and velocity of the process fluid both which act to remove the protective iron sulfide scale that develops as a process of sulfidic corrosion. In general the refinery does not measure or monitor reactive sulfur species but relies on total sulfur measurements. In this case, there is a moderate to high corrosion rate potential based on a theoretical analysis. The operating temperature and total sulfur content of the AGO stream are the primary operating parameters that will be targeted (controllable by the crude slate being run).

- Ttal sulfur at AGO cut (primary IOW).
- Total acid number (TAN) at AGO cut.
- Operating temperature (and time if variable) at X-1 shell.

Step 5 – Reliability Factor Basis (Considerations)

In its current operation, this exchanger has a calculated remaining life of 15 years based on the historical measured corrosion rate (remaining corrosion allowance of 0.075 in. divided by the measured rate of 5 mpy). Utilizing the estimated corrosion rate of 16 mpy the remaining life drops to 4.6 years. To ensure that the exchanger makes it to the next Turnaround (5 years) it was decided to control the corrosion rate to obtain a 6 year remaining life (1 year additional reliability factor).

Step 6 – Set Limits on the Critical Reliability Operating Parameters

Based on a desired operating period of 5 years (turnaround interval) with a 1 year reliability factor, and the remaining or usable corrosion allowance of 0.075 in., it was determined that an allowable corrosion of 12.5 mpy was the maximum rate that could be sustained to make the 6 year run. Two options were given the operations department, 1) control the operating temperature to 622 °F with a total sulfur content of 0.5 wt% or 2) operate at 650 °F and control the total sulfur in the blend at the AGO cut to 0.2 wt% in order to project reliable operation over the specified operating period. In this case, because there is sufficient safety factor remaining even when the thickness reaches the Code t-min value, this was determined to be a medium risk standard IOW.

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