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## Managing an IOW Implementation Program from Development to Sustainment

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## Introduction

Since the publication of API RP 584, “Integrity Operating Windows,” there’ve been increasing requests for integrity operating window (IOW) assessments in the industry [1, 2]. However, in that time, we have observed that:

- The intent of IOWs is not fully understood by some Sites / Organizations.
- IOWs are often defined, but a full management program is not often implemented.
- When implemented, they are not sustained as part of the integrity management program.

The objective of this article is to provide a road map that will help owner-users more cost-effectively implement and sustain an IOW program tailored to their operation.

## What Is an IOW?

An IOW defines the maximum or minimum operating process variables that should be maintained to meet the intended design life of pressure equipment. This is illustrated in **Figure 1**.

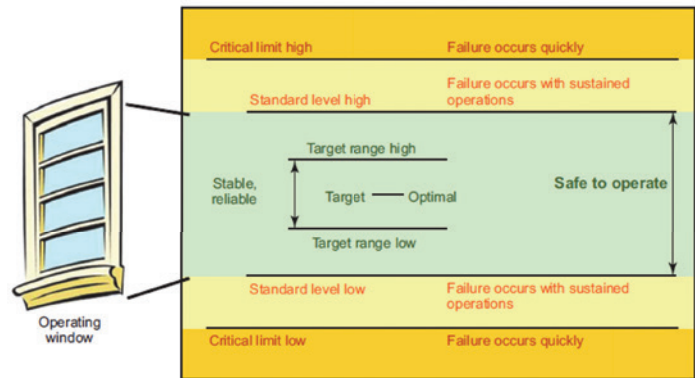
**Figure 1** can be broken down as follows:

- The **green** area represents the estimated norm and the operating conditions for assets to achieve optimal design life.
- The **yellow** area represents conditions that could compromise the design life but do not pose an immediate safety risk. Operation in this area may not require immediate response but often requires close monitoring and involvement of the integrity management team.
- The **orange** area represents the safe operating limit (SOL) boundary. Operation in this area requires immediate action to return the equipment to normal operating conditions, and an engineering assessment should be required to determine the fitness-for-service of the asset.

## Why an IOW Program is Needed

Risk-based inspection (RBI) assessments utilize prior equipment damage rates and process conditions, taken as a snapshot in time, to determine risk and develop/optimize inspection strategies. During day-to-day operations, excursions and upsets that may occur in process conditions are often not fed back into the risk and criticality calculations. When such changes to operating conditions affect key process variables, new damage mechanisms may be introduced or known damage mechanisms may be accelerated, potentially impacting the remaining life of an asset.

A well-established IOW program provides real-time notification of the process changes potentially affecting the integrity



**Figure 1.** Zones of Operation Including Target Ranges with Standard and Critical Limits [1].

of an asset that otherwise may not be accounted for until the next inspection.

## IOW Benefits

There are many benefits of implementing and sustaining a robust IOW program.

- Most importantly, it provides a common platform for communicating ideas, issues, and practices between facility operations, engineering, and maintenance organizations based on a common set of concepts and definitions.
- It provides an established process for recognizing and mitigating the effects of operating plant equipment outside of the design envelope in a real-time environment.
- It facilitates automated data analysis, eliminating the need to review an asset’s past operating history manually.
- If implemented properly, IOWs can provide real-time notifications when any of the predefined boundaries are approaching dangerous territory. This empowers operators with the ability to help form a mitigation plan prior to any damage occurring, resulting in substantial overall savings on inspection frequency, scope, and maintenance costs.

## IOW Criticality

Based on API RP 584, IOWs are classified into different levels, distinguished by risk, to set priorities on notifications (including alarms, alerts, and/or other notifications) and the timing of actions to be implemented when IOWs are exceeded. API RP 584 defines three primary levels of IOWs: “critical,” “standard,” and “informational,” which are based on the predicted change in damage rate to equipment during an exceedance and the ability of the operator to take corrective action.

## Critical IOWs

The criterion for an IOW to reach a Critical level is one where a

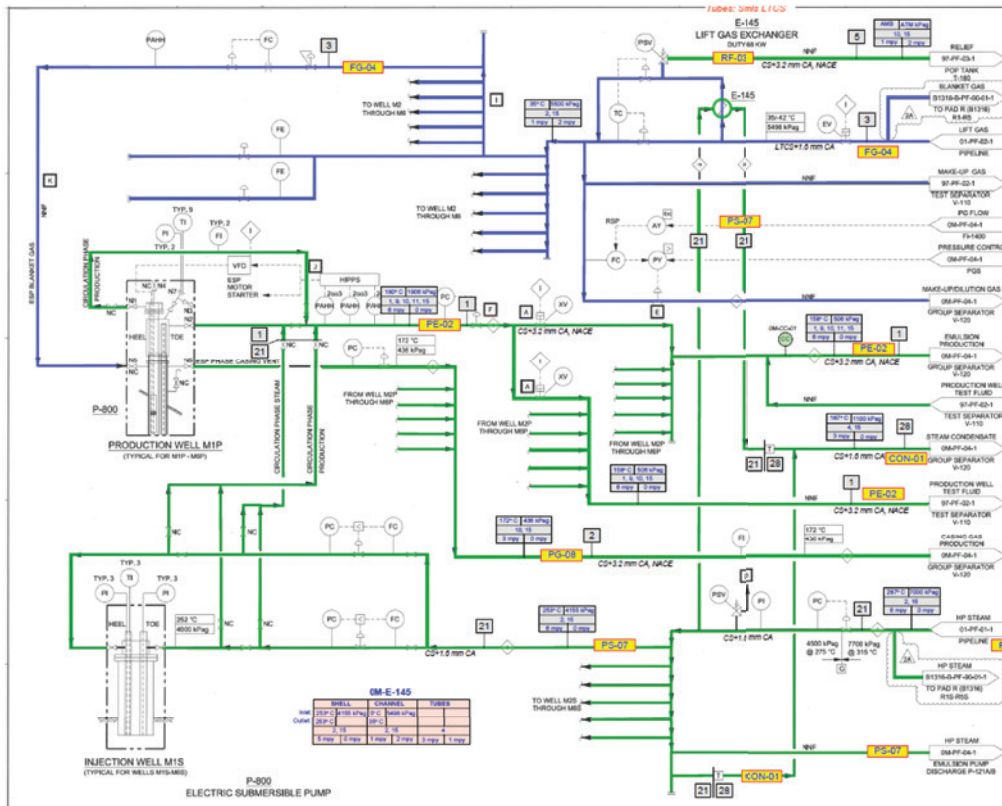


Figure 2. Example of a Corrosion Loop Diagram (partial).

condition, when exceeded, could result in one of the following in a short timeframe:

- Larger and/or quicker loss of containment.
- A catastrophic release of hazardous fluids.
- Emergency or rapid unplanned shutdown.

### Standard IOWs

The criterion for an IOW to reach a Standard level is one or more of the following conditions:

- A safety level is exceeded over a specified period of time and requires predetermined operator intervention or other corrective integrity engineering action in order to bring the process back within the IOW limits.
- Eventual loss of containment.
- Release of hazardous fluids.
- Unscheduled or non-orderly shutdown.
- Negative impact on the long-term unit performance and its ability to meet turnaround duration length.
- Unacceptable financial risk.

### Informational IOWs

Informational IOWs would typically be associated with the following situations:

- Not be directly related to a potential loss of containment within the near term.

- A secondary indication of operational performance or corrosion control issue.
- Tracking/reporting/communicating parameters that are not necessarily controllable by operators but may eventually require action.

Deviations from informational IOWs could eventually lead to accelerated corrosion or other damage over a longer period of time. The limits for informational parameters would be established to provide a point where implemented software would typically initiate a notification to an integrity engineer.

### IOW Development

Development of IOWs is a relatively straightforward process, especially if done in parallel with or following an RBI assessment. The steps are as follows:

1. Collect and Analyze Data
2. Conduct Corrosion Loop Analysis
3. Conduct IOW Criticality Analysis
4. Document IOW Analysis
  - Populate IOW Summary Workbook
  - Update of CCD corrosion circuit diagram P&IDs, indicating the locations of the sensors or sampling points

### IOW Development: Collect & Analyze Data

For this step, the primary data sources are corrosion control diagrams (CCD), corrosion loop drawings (see Figure 2 for an example), and RBI summaries or data on which they are based (e.g.,

P&IDs, PFDs, U-1 forms, piping specifications, etc.).

The information obtained from this review includes:

- Corrosion loops and boundaries
- Included equipment and piping circuits
- Process fluids and conditions
- Applicable damage mechanisms
- Assigned risk (POF, COF)
- Inspection frequencies

### IOW Development: Corrosion Loop Analysis

During this step, criticality is assigned based on the highest COF of the corrosion loops' fixed equipment and piping circuits, typically completed at the process flow diagram level. Furthermore, applicable damage mechanisms should be assigned to the corrosion loops. These systems are also sometimes transposed down into or onto corrosion circuits created at the P&ID level.

### IOW Development: IOW Criticality Analysis

Establishing the "critical," "standard," and "informational" limits for IOWs separates IOWs based on 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 IOWs (i.e., "critical" limits), additional prioritization can be achieved through risk ranking the "standard" and "informational" limits.

**Table 1.** Example Risk Matrix.

| Risk Assessment Matrix  |            |                              |             |             |             |              |
|-------------------------|------------|------------------------------|-------------|-------------|-------------|--------------|
|                         |            | Consequence Severity Ranking |             |             |             |              |
|                         |            | Insignificant                | Minor       | Moderate    | Major       | Catastrophic |
| Cause Frequency Ranking | Frequent   | Low                          | Significant | Critical    | Mega        | Mega         |
|                         | Probable   | Low                          | Significant | Significant | Critical    | Mega         |
|                         | Occasional | Low                          | Low         | Significant | Significant | Critical     |
|                         | Remote     | Negligible                   | Low         | Low         | Significant | Significant  |
|                         | Improbable | Negligible                   | Negligible  | Low         | Low         | Low          |

### IOW Development: Assign Risk

As indicated in the example risk matrix illustrated in Table 1, the risk of an item can be classified into one of five categories.

The risk value, in combination with the classification, is used to determine recommended actions following an IOW exceedance.

### IOW Development: Document IOW Analysis

IOWs can be documented by populating an IOW summary Excel® Workbook (displayed in **Tables 2** and **3**) and through the markup of P&IDs (see **Figure 3**) with the location of instruments used to measure the parameters defining each IOW.

### IOW Implementation

IOW implementation is the most difficult step in setting up a sustainable IOW program, requiring significant input and coordination between operations, integrity engineering, and maintenance.

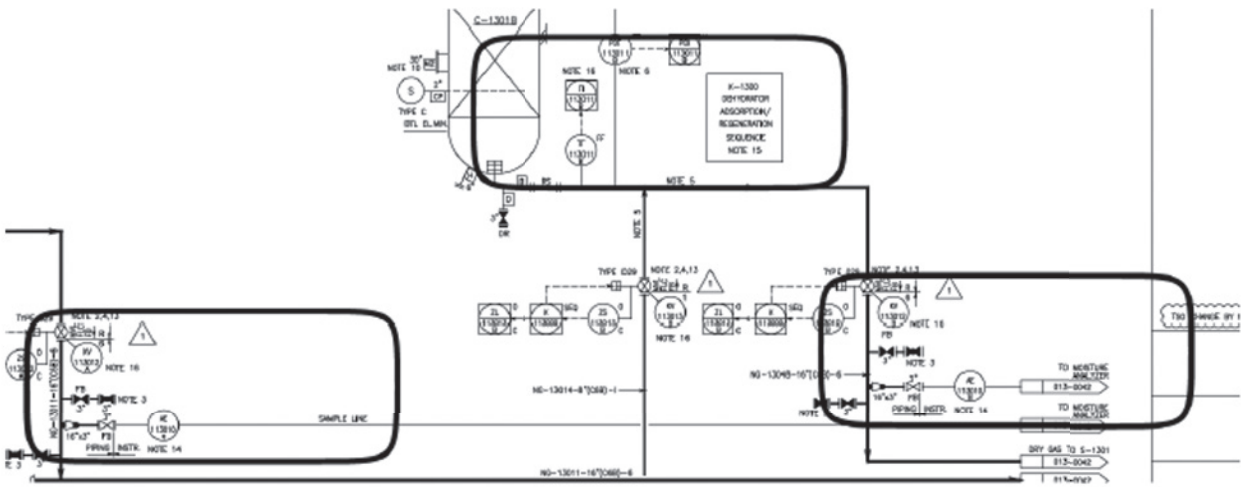
During the IOW implementation phase, the following tasks must be completed:

**Table 2.** IOW Summary Sheet, Part A.

| IOW Item | Reference DL Drawing | Damage Loop Number | Equip and/or Piping Circuits (Start-Stop)   | Monitoring Type Tag No. | Monitoring Frequency                | Relevant Damage Mechanism(s)   | Process Variable     |                  |   |      |                              |      |        |            |            |
|----------|----------------------|--------------------|---|-------------------------|-------------------------------------|--------------------------------|----------------------|------------------|---|------|------------------------------|------|--------|------------|------------|
|          |                      |                    |   |                         |                                     |                                | Fluid Velocity (m/s) | Temperature (°C) |   |      | Contaminant #1 Concentration |      |        |            |            |
| N/A      | 103-PP-D-402         | 1C                 | Bypasses on 103-E1A and 103-E-EB from spec break and 103-E-1A 4/B4/C4/D4 Shell side   | -                       | As required by operations practices | Uniform Corrosion (See Note 2) | -                    | -                | - | -    | -                            | -    | -      | -          | -          |
| 3        | 103-PP-D-402         | 1C                 | 103-E-1A 4/B4/C4/D4 Shell side  | N/A                     |                                     | High Temp H2/H2S Corrosion     | -                    | -                | - | >320 | >300                         | <260 | -      | >0.5mol% S | >1mg/g Tan |
| 4        | 103-PP-D-403         | 2A                 | Quench gas from 103-K-1 to reactors 103-D-1A (from Tie-in 103-003-005), 103-D-2A (from Tie-in 103-003-011,012), 103-D-3A (from Tie-in 103-004-002), 103-D-18 (from Tie-in 103-016-003), 103-D-2B (from Tie-in 103-016-011, 012), 103-D-2C (from Tie-in 1073-017-002). | N/A                     |                                     | Wet H2S                        | -                    | -                | - | <150 | -                            | -    | >50ppm | -          | -          |

**Table 3.** IOW Summary Sheet, Part B.

| IOW Item | Recommended Action of IOW Exceeded   | Damage Mechanism Comments  | Summary Comments   | Notes   |
|----------|--|--|--|---|
|          | (See Note 1)   |  |  | 1   |
| N/A      | N/A  | Uniform Corrosion is the anticipated corrosion mechanism based on the process conditions. (See Note 8)   | Uniform corrosion within the design constraints for the equipment should not be influenced significantly by process operations conditions, and therefore the IOW limits are ultimately set for the design conditions of the individual assets within the loop.   | <p>Damage mechanism analysis based on rate of damage:</p> <p><b>High alert:</b> High likelihood of failure (LOF) when operated continuously outside integrity operating window (IOW) for 0-7 days—high-consequence-of-failure (high-COF) circuits require monitoring and/or mitigation.</p> <p><b>Medium alert:</b> High likelihood of failure (LOF) when operated continuously outside integrity operating window (IOW) for 7-364 days.</p> <p><b>Low alert</b></p> <p>If operated in this area, immediate action should be taken to return to operating conditions, and engineering should be consulted as to possible fit-for-service.</p> <p>Monitor closely; inform Risk-Based Inspection (RBI) team; recommend a Remaining Life Analysis and return of operating parameter(s) exceeded to normal target if possible.</p> <p>Action not normally required.</p> |
| 3        | Normal continuous operations is at the Low Alert (Green) status. Typically, IOW actions are not recommended. Review of the operating conditions and the inspection records is the recommended action, unless the high level is reached during service. | High Temp H2/H2S corrosion has been selected as the equipment operates in the temp range at which H2/H2S corrosion is as concern. Increasing the H2S contaminant will and/or temperature will increase the likelihood damage will occur. | Likely, continuous operations at or near the design limits with higher concentrations of H2S may be required for damage to accumulate. Inspections for High Temp H2/H2S are recommended as part of the integrity program.<br><br>103-EIX4 has material of construction of SA 336 F11 and an operating temperature approximately 248°C. At the reported operating conditions the material has limited susceptibility to corrosion, but process upsets may cause High temp H2/H2S corrosion. | 2   |
| 4        | Assess possible wet H2S damage and inspect as required.  | Wet H2S damage is likely to occur if the concentration of H2S increases over 50ppm in a process upset.   | The circuit has no information that the material of construction is Sour/NACE compliant. While the circuit is PWHT, Blistering and HIC might be possible if the steel is not NACE compliant.   | 2   |
|          |  |  |  | 3   |
|          |  |  |  | 4   |
|          |  |  |  | 5   |
|          |  |  |  | 6   |



**Figure 3.** Example of Marked-up P&ID.

- Response strategies
- IOW/DCS integration
- Interrogate data historian
- Corrective action implementation and management

**IOW Implementation: Response Strategies**

**Table 4** provides a matrix by which guidelines can be established for the risk and criticality of each defined IOW.

The primary factor in determining the difference between critical and standard limits is 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; specific predetermined actions are to

be taken by the operator to return the process to within the IOW limits urgently.

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.

**IOW Implementation: IOW/DCS Integration**

This task will require the inclusion of instrument engineering. IOWs should be programmed into the distributed control system (DCS) or plant historian software to alarm/notify responsible parties and aid in documentation.

Implementation of the IOWs into the distributed control system optimizes the effectiveness of the IOW limits. It limits the burden on operators to respond to an additional set of alarms.

**Table 4.** IOW Implementation Response Matrix.

| Risk        | Classification            | IOW Guidance/Action   |
|-------------|---------------------------|---|
| Mega        | Critical                  | IOWs required - Limits and durations established on all IOW parameters for monitoring IOWs are alarmed/ alerted and IM engineers are notified of exceedance.<br><br>Operations takes urgent predetermined action to return process to normal operation. |
| Critical    | Critical or Standard      | IOWs required - Limits and durations established on all IOW parameters for monitoring IOWs are alarmed/ alerted and SMEs are notified of exceedance.<br><br>Operations takes urgent predetermined action to return process to normal operation.         |
| Significant | Standard or Informational | IOW Informational Limits (ILL) identified. Suggested limits specified for each IOW. Operations and IM Engineers alerted/notified of exceedances.<br><br>Troubleshooting initiated with planned adjustments to operations and inspections developed.     |
| Low         | Informational             | ILLs suggested. Normal operating parameters identified for analysis; parameters tracked and trended by IM engineers to determine long-term effects on equipment reliability.  |
| Negligible  | No IOW                    | No ILLs suggested.  |

In some instances, IOWs may be identified, which may not be monitored through instrumentation. These may require fluid sampling to determine pH, acid or contaminant levels, for example. Non-instrument IOW action may be a local measurement that needs to be included in operator rounds.

**IOW Implementation: Interrogate Data Historian**

To access data that has been downloaded to the DCS historian, standard queries as well as a specialized dashboard for unique queries should be developed. These queries are required to obtain and list IOW exceedances written to the DCS historian software to assist in the analysis as a basis for correction strategies.

They will also allow trending of operating data for IOW parameter sensors to ascertain whether operating behavior has changed over time.

**IOW Implementation: Corrective Action Implementation and Management**

An often overlooked aspect of many programs is the lack of a formal team to investigate and manage corrective actions after an incident.

A formal team to investigate and manage IOW corrective actions is recommended. At a minimum, the organization should include integrity engineering, operations, and maintenance (Chief Inspector), and a manager should be assigned for this task. It is recommended that the manager be from integrity engineering. Once roles are determined, the team should develop and implement a communication strategy.

The corrective action management scope should include the following:

- Definition of the team’s roles and responsibilities.
- Review of the incident / exceedance (level of exceedance, causes, duration, potential for equipment degradation, etc.)
- Review of organizational response to exceedance
- Review the need for additional assessment (on-stream inspection or other data analysis)

- Determination of the means for risk mitigation (operating or design change, additional training, etc.).
- Consider the need for longer term assessment (ongoing or during the next turnaround) and if the current inspection strategy (scope, frequency, techniques & locations) needs modification

**Sustainment**

Often, programs such as those for managing piping, RBI, IOWs, etc., fall into disuse because of a lack of triggers for change or a lack of management interest.

To counter the falloff of interest in these programs, it is recommended that:

- Ongoing sustainment should be included as a facility management annual KPI.
- Funding for sustainment should be included in annual resource budgets.
- An individual should be assigned the authority and responsibility for managing the program.
- IOW reassessment should be included in the management of change (MOC) process.
- Define reassessment triggers:
  - Inspection results
  - Change in design and/or operations
  - Change in feedstock and/or product slate
  - Change in regulatory requirements

**Conclusion**

While there are no benefit/cost analyses in the public domain or from those who have implemented IOWs, it can be argued that a positive cost/benefit case for IOW implementation could be made. The author has been involved in developing IOWs that have varied from \$100,000 to \$300,000 (US). Add to that another \$100,000 to \$150,000 investment on behalf of the owner-user to implement IOWs into the DCS and plant historian, for a total investment of \$500,000.

Countering the investment cost is a reasonable probability, absent implementation of IOWs, of a process overrun that could result in either loss of revenue exceeding a million or more dollars or a significant challenge to health, safety, or the environment, again resulting in multi-million-dollar losses.

Given the above, it can be concluded that investment in a sustainable IOW program will bring a positive return to an owner-user. ■

For more information on this subject or the author, please email us at [inquiries@inspectioneering.com](mailto:inquiries@inspectioneering.com).

REFERENCES

1. API RP 584, 2014, “Integrity Operating Windows,” First Edition, American Petroleum Institute.
2. API RP 584, 2021, “Integrity Operating Windows,” Second Edition, American Petroleum Institute.



### **Stephen C. Hall**

Steve has over 40 years of experience in managing and performing risk, reliability, and availability analysis with a background well suited for addressing risk, operating reliability, and life cycle cost issues. In addition to performing risk, reliability, availability, and life cycle cost analyses of refinery, chemical, electric power, and marine systems, he has also managed the development and maintenance of risk and reliability software applications.