ANALYSIS OF HUMAN FACTORS FOR PROCESS SAFETY: APPLICATION OF LOPA-HF TO A FIRED FURNACE

by

Paul Baybutt
Primatech Inc.

and

Joel Haight
The Pennsylvania State University

Abstract

Layers of Protection Analysis for Human Factors (LOPA-HF) is a new approach for addressing human factors in process safety. It employs the framework of standard LOPA but focuses on the human factors that impact the various elements of hazard scenarios. Scenarios are screened for analysis using PHA. Its use is illustrated in an application to a fired furnace.

Introduction

OSHA's Process Safety Management (PSM) standard, 29 CFR 1910.119 and EPA's Risk Management Program (RMP) rule, 40 CFR Part 68 require that a Process Hazard Analysis (PHA) be performed for processes covered by the regulations and that, among other things, "the PHA shall address human factors". Both the human failures that can cause accidents and the human factors that can influence them must be addressed. Examples of human factors issues that OSHA is concerned about, and that can contribute to hazard scenarios, include the accessibility, clarity and usability of controls and instrumentation, task overload and work schedules(1).

Common approaches for identifying the human factors that influence human failures in PHA involve the use of checklists. Unfortunately, such checklist approaches are cumbersome, and quickly become repetitive and tiresome. There is a need for an improved method that is both efficient and effective in helping to control process risk. LOPA-HF was developed to address this need(2). It applies the framework and methods of Layers of Protection Analysis (LOPA), a simplified risk assessment method(3).

Engineering judgment is used in PHA to decide what additional safeguards may be needed to prevent, detect, or mitigate hazards. These subjective assessments can lead to disagreements, and possibly inappropriate measures to reduce risk. It was recognized that a more rational, objective and reproducible approach was needed, at least when considering risk remediation measures for high risk scenarios. This led to the development of LOPA.

Layers of Protection Analysis

LOPA is used to analyze individual hazard scenarios defined by cause-consequence pairs. It considers safeguards that are Independent Protection Layers (IPLs), defined as those whose failure is independent of any other failures involved in the scenario. To approximate the risk of a scenario, LOPA typically uses order of magnitude categories for the initiating event frequency, the likelihood of failure of IPLs and the consequence severity. Scenario frequency is determined by combining the initiating event frequency, IPL failure probabilities, and probabilities of enabling events / conditions. Scenario risk is determined by combining scenario frequency and consequence severity and is compared to risk tolerance criteria to determine if additional risk reduction is required to reach a tolerable level.

LOPA follows a set procedure in which high risk scenarios are first identified for consideration using PHA. Each of these scenarios is then analyzed. A key part of this analysis involves determining the Safety Integrity Level (SIL) provided by the IPLs involved in the scenario. The SIL is usually defined as a Probability of Failure on Demand (PFD). This is the probability the IPL fails to perform its required safety function on demand.

LOPA can be viewed as an extension of Process Hazards Analysis (PHA). Typically, it is applied after a PHA has been performed. LOPA builds on the information developed in the PHA. It is used to assess scenario risk and compare it with risk tolerance criteria to decide if existing safeguards are adequate, and if additional safeguards are needed.

LOPA-HF

In order to address the impact of human factors on process risk, it is necessary to examine how people are involved with individual hazard scenarios since the scenarios determine process risk. This entails examining the impact of human factors on the constituent elements of hazard scenarios, namely the initiating event, or cause of the scenario, intermediate events that can include operator actions as well as automated responses of the process control and safety systems, enabling events or conditions that must be present or active for the scenario to proceed, and the consequence or effect of the scenario on people (on-site or off-site), property (on-site or off-site), the process (downtime, product quality, etc.), the environment, etc. LOPA-HF is used to identify and assess the human factors that impact these constituents of hazard scenarios using an approach based on Layers of Protection Analysis (LOPA).

The analysis of human factors for hazard scenarios using LOPA methods can be performed as an adjunct to a standard LOPA study or independently.

Application of LOPA-HF to a Fired Furnace

A drawing of a bottom-fired furnace is shown in Figure 1. Table 1 and Figure 2 provide an operating procedure and a checklist for startup of the furnace. Both the drawing and the procedure are simplified for the purposes of this example.

Process Description

The natural draft, bottom-fired furnace is fueled by natural gas to four piloted burners. Draft is controlled by a stack damper and burner registers. The stack and fire box are supplied with steam to purge the fire box and snuff an accidental fire, if needed. Once established, natural gas flow is automatically controlled by flow to the burners. It is also controlled by flame detectors on the pilot system. Upon loss of flame, the fuel supply is cut off. Fuel supply is also cut off on loss of hydrocarbon feed to the tubes to prevent overheating and possible tube rupture. The operator is provided with fire box temperature readings and fuel gas pressure readings to assist in running an efficient operation.

Hydrocarbon feed is fed to the furnace for pre-heating at a rate of 670 gpm, at 250 F and 350 psig. The feed rate is controlled by flow to the furnace tubes and by natural gas flow. The feed is cut off on loss of natural gas flow and on loss of flame to burners. Feed flows through the furnace fire box in a series of circular passes from the bottom of the fire box to the top where it is discharged to a series of exchangers at 670 gpm, 390 F and 250 psig. The startup process for the furnace is manual.

Process Hazard Analysis

On the basis of a risk ranking performed in the PHA for the furnace, three hazard scenarios were selected for demonstration of LOPA-HF. These were risk ranked at level 4 or 5 which is a relatively high risk value. The PHA worksheets showing these scenarios are provided in Figure 3. The scenarios are summarized in Table 2.

LOPA-HF For Furnace Startup

In LOPA-HF the dominant human factors contributors to the failure rate, existing protective measures and any recommendations for additional protective measures are considered for each constituent element of each selected hazard scenario (see LOPA-HF flowchart in Figure 4).

The analysis starts with the initiating event for the first scenario. A simple Human Factors Issues List (see Example in Table 3) is used to identify the dominant human factors that contribute to the initiating event. More than one may be identified. This information is recorded in a LOPA-HF worksheet (see Figure 5). For example, in the case of the initiating event: “Operator blocks in feed flow to furnace tubes by inadvertently giving wrong instruction to the control room”, the LOPA-HF analysts identified the dominant human factors of “Operator confused by noisy working environment” and “Static on radios causes mis-communication”.

LOPA-HF analysts next consider protective measures that may be in place for the initiating event. They consider items on a Protective Measures Issues List (see example in Table 4). In the case of the initiating event for the first scenario, no existing protective measures were identified (Figure 5). However, for the second scenario with the initiating event “Operator does not perform LEL check”, the protective measure of “Training of operator” was identified.

LOPA-HF analysts next consider whether additional protective measures should be in place for the initiating event. This decision can be made using the standard LOPA technique of comparing estimated scenario risk with risk tolerance criteria. If risk reduction is needed, consideration can be given to reducing the frequency of the initiating event by providing additional protective measures. LOPA-HF analysts use a Protective Measures Issues Lists as a guide (see Table 4). In the case of the initiating event for the first scenario, the recommendation “Consider switching to higher frequency radios” was identified.

This analysis is repeated for the IPLs, enabling events/conditions and the scenario consequence and is performed for all scenarios screened using PHA (see Figures 5 -

7). Although LOPA-HF addresses enabling events/conditions in a similar way to initiating events and IPLs, there is an additional first step of identifying applicable enabling events/conditions since they may not have been identified or considered in the PHA. This is done by reviewing an Issues List of enabling events/conditions (see example in Table 5).

LOPA-HF Issues Lists are customized for various types of human failures and should be standardized so that LOPA-HF analysts become accustomed to working with them. They can be customized for particular types of processes and/or specific companies' cultures.

Evaluating The Impact of Risk Reduction Measures on Scenario Likelihood

Once the human factors issues that adversely affect the performance of the constituent elements of the hazard scenario have been identified, the contributions of corrective actions to reducing the scenario likelihood can be assessed. Their effects will combine together through reductions in the likelihoods of the initiating event, intermediate events, enabling events/conditions and consequences. Their impact on each of these likelihoods can be estimated individually in a similar way to assessing SIL improvements in IPLs from design improvements using standard LOPA.

Human failure probabilities (HFP) can be used to represent the probability of failures by people such as operators when faced with the need to act. They address both inaction and incorrect action (errors of omission and commission). They are analogous to PFDs (probability of failure on demand) used for independent protection layers (IPLs) in standard LOPA.

Alternatively, an approach can be used in which credits are assigned for each type of human factors improvement according to its effectiveness(2). The approach involves assigning credits to human factors recommendations. When aggregated, each 10 credits of improvements contributes an order of magnitude reduction in the scenario likelihood. The aggregation is made for human factors improvements regardless of the event or condition in the hazard scenario that they impact and regardless of whether the event is a human failure (represented by a HFP) or another type of failure (represented by a PFD) thus simplifying the analysis considerably. The use of credits also facilitates deciding between alternative improvements since their relative contributions to risk reduction are made obvious. A target risk level can be met by accumulating sufficient credits and the analysts can decide which of various possible combinations are preferred. The use of credits is illustrated for the furnace example in Table 6 where recommendations from the LOPA-HF study are assigned credits.

Strategies for reaching a tolerable risk level can now be devised. It may be desired to reduce the risk of all three scenarios by an order of magnitude. The fix is obvious, i.e. automate startup. That provides a total 10 credits which is equivalent to an order of magnitude reduction in scenario risk in the LOPA-HF scheme. However, that may not be feasible and other actions may be required. For example, in the third scenario, ensuring the operator does not perform other tasks while starting the furnace and providing regular refresher training to contract mechanics. may be judged adequate since they produce a total of 6 credits.

Conclusions

A better way of addressing human factors in PHA is needed owing to their importance and likely dominant role in contributing to process risk. LOPA-HF is an improvement over conventional approaches. The analysis approach is straightforward as illustrated in this application to a fired furnace. LOPA-HF takes advantage of the development over the past few years of the LOPA framework and methods which have been proven effective in evaluating process safeguards[3].

BIBLIOGRAPHY

1) CPL 2-2.45A CH-1 - Process Safety Management of Highly Hazardous Chemicals-- Compliance Guidelines and Enforcement Procedures, Occupational Safety and Health Administration, September 13, 1994.

2) Baybutt, P., Layers of Protection Analysis for Human Factors, Process Safety Progress, Accepted for publication, June, 2002.

3) Layer of Protection Analysis, Simplified Process Risk Assessment, AIChE/CCPS, 2001.

4) Baybutt, P. "Human Factors in Process Safety and Risk Management: Needs for Models, Tools and Techniques", P. Baybutt, Proceedings of the International Workshop on Human Factors in Offshore Operations, US Minerals Management Service, New Orleans, pps 412 - 433 (December, 1996).

Acknowledgments

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Table 1. Standard Operating Procedure for Furnace Startup.

WARNING!
Furnace startup poses the risk of explosions owing to the possibility of explosive fuel gas-air mixtures in the furnace if this procedure is not followed correctly.

1. MAINTAIN radio contact with the control room while performing this procedure.

2. OPEN stack damper.

3. OPEN burner registers.

4. ALLOW Fire Box to vent for two minutes.

5. PURGE Fire Box with steam for two minutes.

6. ALLOW Fire Box to vent for two additional minutes.

7. PERFORM Fire Box Air Tests for Oxygen Concentration and LEL.

8. IF Oxygen concentration is high,

   THEN, CLOSE stack damper.

9. IF Oxygen concentration is low,

   THEN, OPEN burner registers.

10. IF Oxygen concentration and LEL are acceptable,

    THEN, OPEN manual valves on Pilot Assembly one at a time.

NOTE
There are 4 valves.

11. IGNITE Pilots manually.

NOTE
There are 4 Pilots.

12. WHEN all 4 Pilots are established,

    THEN, OPEN burner header valves manually to minimum flow for each

NOTE
There are 4 burner header valves.

13. WHEN burner fires are established on minimum,

    THEN, ESTABLISH feed flow to tubes from control room.

- END -

Table 2. Summary of High Risk Scenarios From PHA.

INITIATING EVENT	CONSEQUENCE	SAFEGUARDS	ENABLING CONDITIONS / EVENTS
Operator blocks in feed flow to furnace tubes by inadvertently giving wrong instruction to the control room.	Potential tube rupture and subsequent explosion after feed stock pours into fire box (burners would normally be on) and possible exposure of furnace operator to explosion.	Feed flow controls the gas flow and the system will block in fuel supply on loss of feed flow.	None
Operator does not perform LEL check.	Potential (partially confined) explosion / detonation if large vapor cloud in fire box is ignited and possible exposure of furnace operator to explosion.	Procedure requires testing (LEL and O_2) of fire box after purging and prior to establishing fuel gas flow to burners.	Ignition source / pilots lit
Operator establishes fuel flow without igniting pilot.	Fire box fills with fuel and presents a potential for fire or explosion when fuel finds an ignition source. Possible exposure of furnace operator to fire or explosion.	Flame detector on pilot will automatically shut off fuel flow if no flame is detected.	Ignition source

Table 3. Example of Human Factors Issues List for “Incorrect Action by Operator”.

HUMAN FACTORS ISSUES LIST
Incorrect Action By Operator
Work overload/underload
Insufficient training
Inadequate skills
Inadequate resources
Inadequate procedures
Inadequate labeling
Equipment not easily operable
Displays/controls not visible/heard
Displays/controls confusing
Displays/controls not accessible/usable
Inadequate communications
Environmental issues (temperature, humidity, light, noise, distractions)
Error (wrong action, no specific reason)
Mistake (wrong action, misunderstood)
Other?

Table 4. Example of Protective Measures Issues List for “Incorrect action by operator”.

PROTECTIVE MEASURES ISSUES LIST
Incorrect Action by Operator
Training
Procedures
Equipment labeled
Check
Other?

Table 5. Example of Enabling Events/Conditions Issus List .

ENABLING EVENTS/CONDITIONS ISSUES LIST
Installation of incorrect seals, gaskets, etc.
Process left in incorrect state after turnaround, maintenance, sampling, or other operation
Disabled alarms
Overrides
LOTO not effected
Startup/shutdown/operating/emergency mode, etc.
Ignition source present
Other?

Table 6. Human Factors Recommendations from LOPA-HF Study.

RECOMMENDATION	CREDITS
Consider switching to higher frequency radios.	2
Consider installing pressure transmitter with control room indication and monitoring.	3
Consider installing local high pressure alarm.	2
Consider automating furnace startup.	10
Consider requiring LEL test to be performed by a different operator.	3
Place additional Warning in furnace startup procedure immediately prior to LEL test step.	2
Ensure furnace operator does not perform other tasks while starting furnace as a matter of policy.	4
Consider use of redundant diverse test equipment.	2
Consider requiring second LEL test by another operator for confirmation.	3
Consider providing fuel valve position indicators.	1
Provide regular refresher training to contract mechanics.	2

Figure 1. Drawing for Bottom-Fired Furnace.

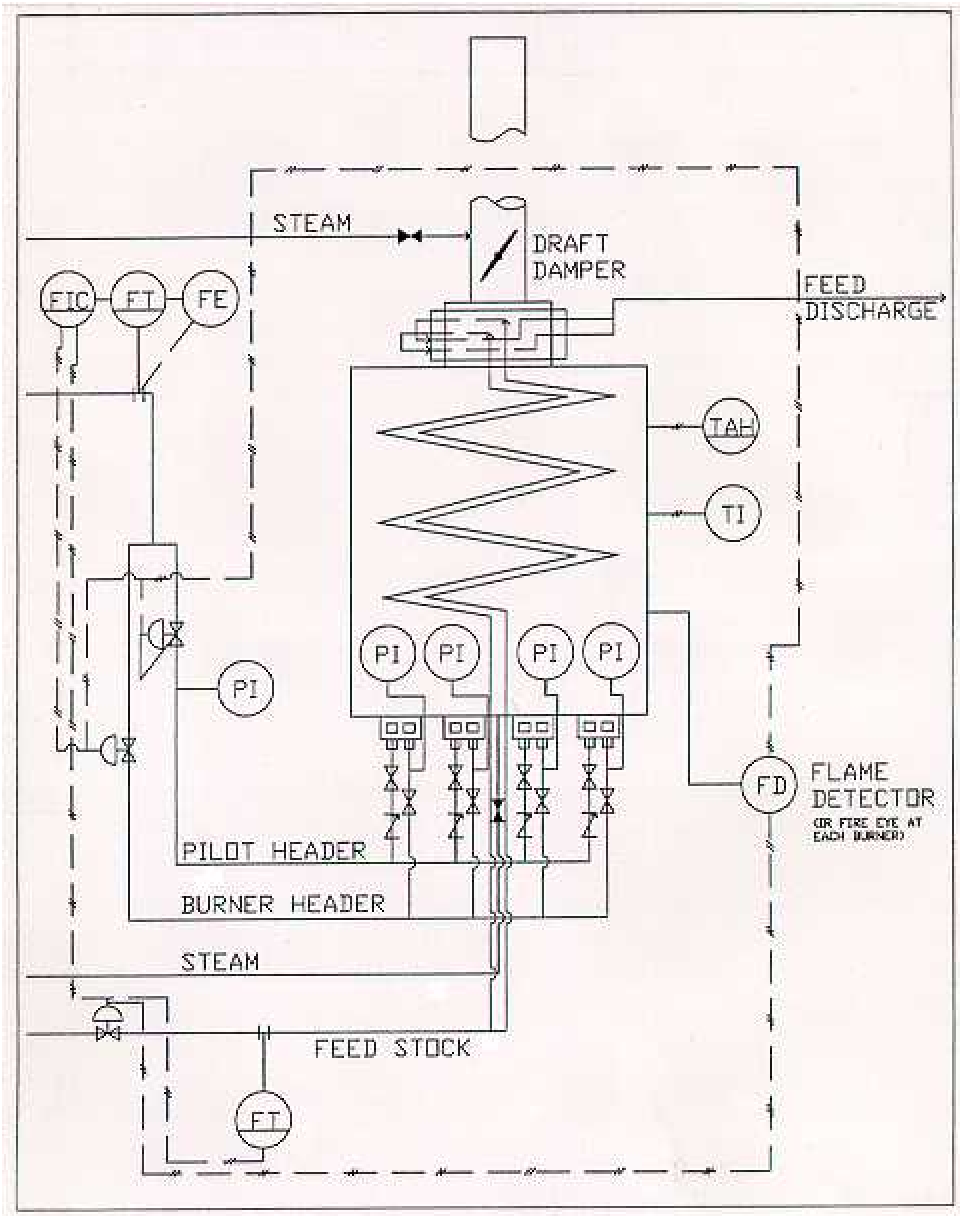
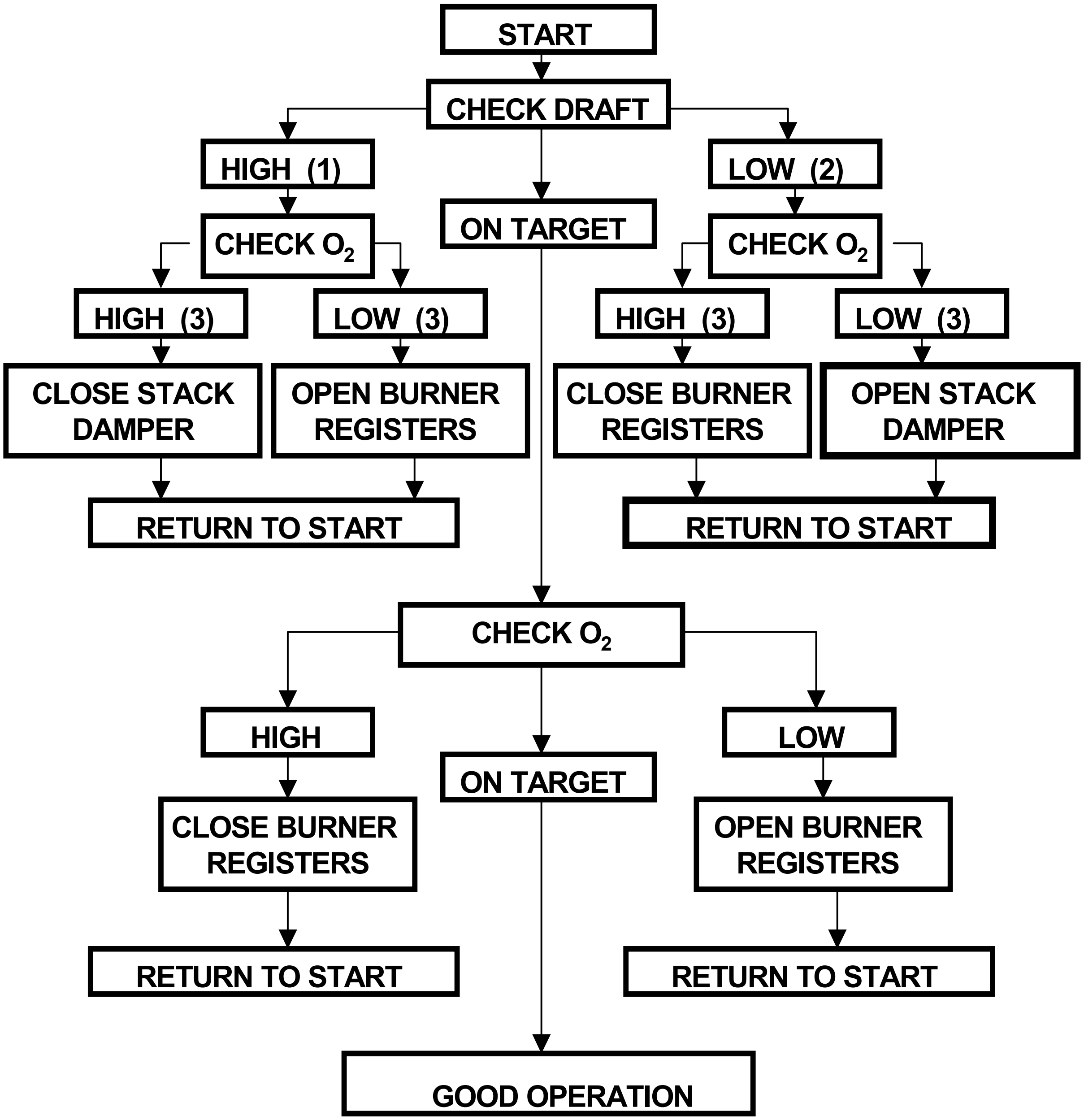


Figure 2. Furnace Startup Checklist.



NOTE:

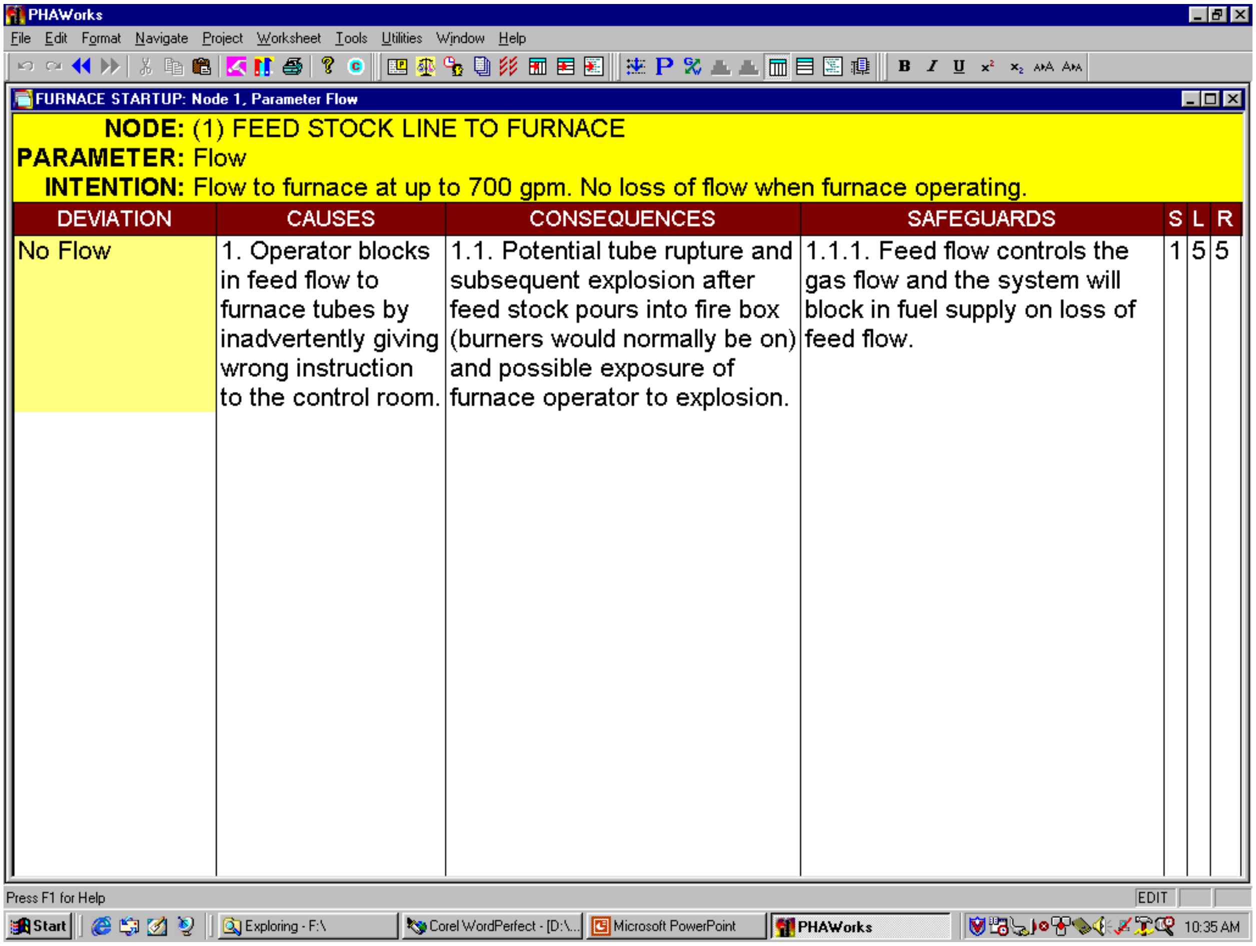
1) High Draft – Means fire box pressure more negative than target

2) Low Draft – Means fire box pressure more positive than target

3) High or Low O_2 – Means O_2 is above or below target

<u>Figure 3. HAZOP Worksheets for Furnace Startup Example.</u>

<u>Scenario 1:</u>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FURNACE STARTUP: Node 1, Parameter Flow

NODE: (1) FEED STOCK LINE TO FURNACE

PARAMETER: Flow

INTENTION: Flow to furnace at up to 700 gpm. No loss of flow when furnace operating.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	S	L	R
No Flow	1. Operator blocks in feed flow to furnace tubes by inadvertently giving wrong instruction to the control room.	1.1. Potential tube rupture and subsequent explosion after feed stock pours into fire box (burners would normally be on) and possible exposure of furnace operator to explosion.	1.1.1. Feed flow controls the gas flow and the system will block in fuel supply on loss of feed flow.	1	5	5

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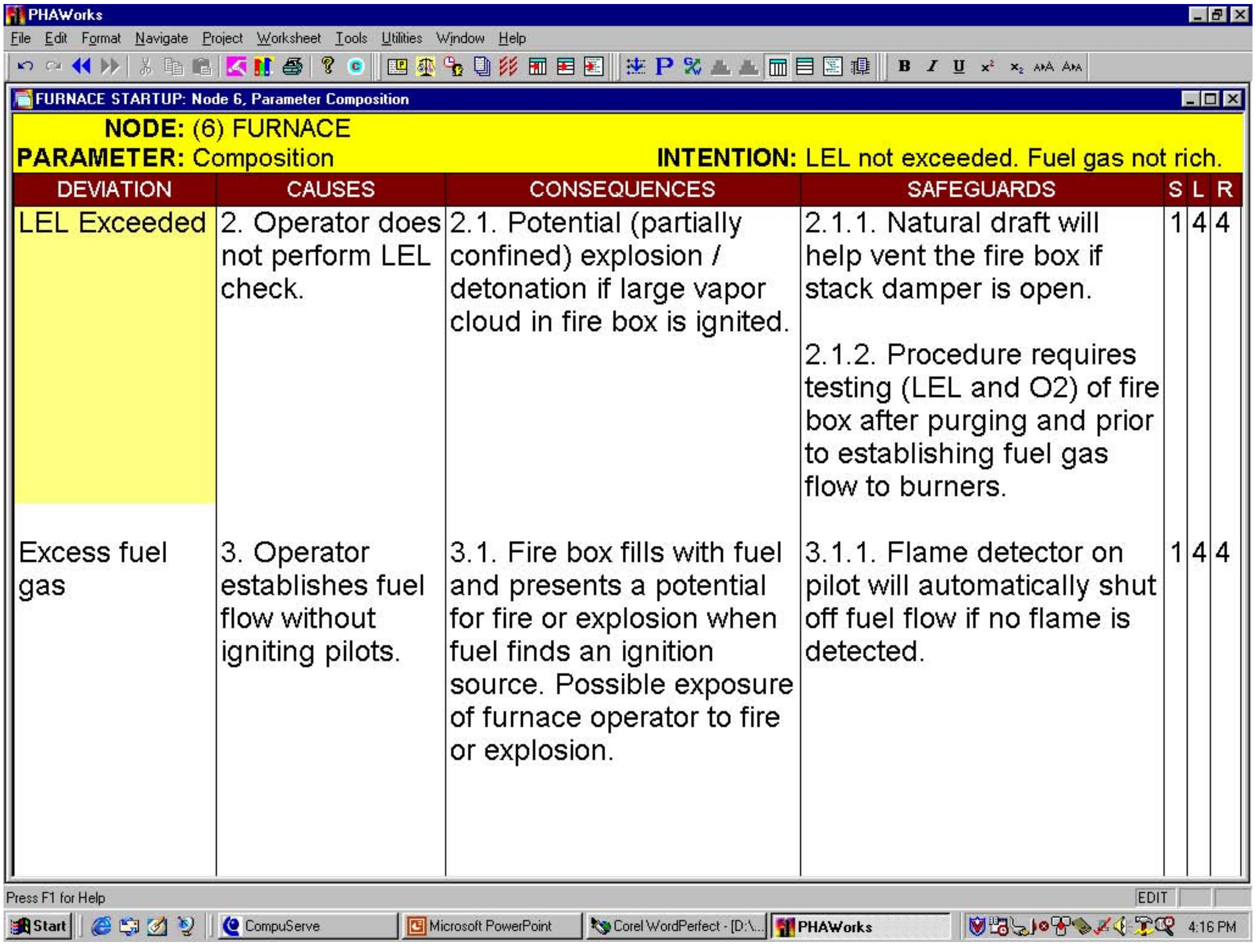
Scenarios 2 and 3



FURNACE STARTUP: Node 6, Parameter Composition

NODE: (6) FURNACE

PARAMETER: Composition **INTENTION:** LEL not exceeded. Fuel gas not rich.

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	S	L	R
LEL Exceeded	2. Operator does not perform LEL check.	2.1. Potential (partially confined) explosion / detonation if large vapor cloud in fire box is ignited.	2.1.1. Natural draft will help vent the fire box if stack damper is open. 2.1.2. Procedure requires testing (LEL and O2) of fire box after purging and prior to establishing fuel gas flow to burners.	1	4	4
Excess fuel gas	3. Operator establishes fuel flow without igniting pilots.	3.1. Fire box fills with fuel and presents a potential for fire or explosion when fuel finds an ignition source. Possible exposure of furnace operator to fire or explosion.	3.1.1. Flame detector on pilot will automatically shut off fuel flow if no flame is detected.	1	4	4

Figure 4. LOPA-HF Flowchart

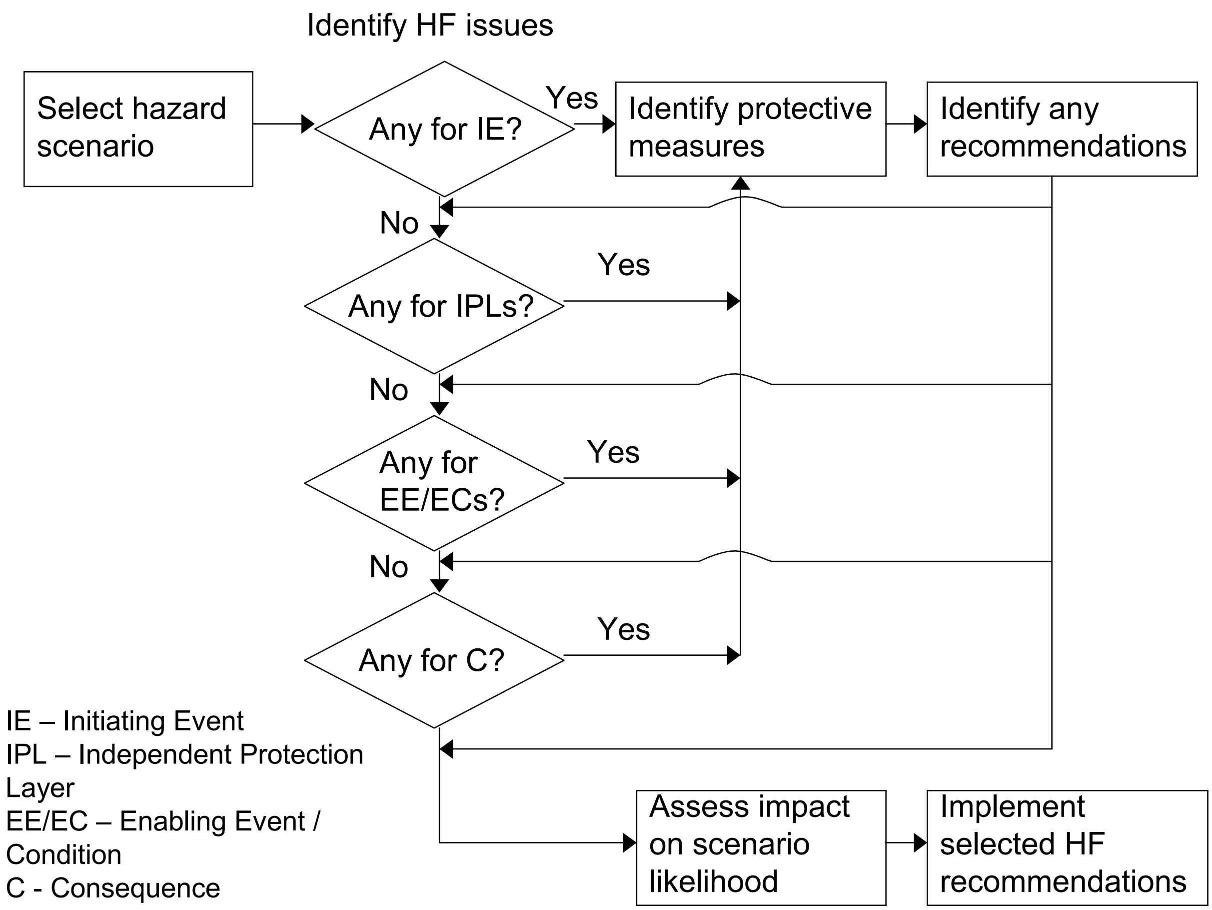


Figure 5. LOPA-HF Worksheet For Furnace Startup - Scenario 1

LOPA - HUMAN FACTORS WORKSHEET	
Scenario Description: Feed flow blocked in causing possible furnace tube rupture and explosion.	
Initiating event: Operator blocks in feed flow to furnace tubes by inadvertently giving wrong instruction to the control room.	
Human Factors:	Operator confused by noisy working environment. Static on radios causes mis-communication.
Protective Measures:	None
Recommendations:	Consider switching to higher frequency radios.
IPL 1: Fuel supply blocked in on loss of feed flow.	
Human Factors:	None
Protective Measures:	-
Recommendations:	-
IPL 2: Local pressure gauges.	
Human Factors:	Operator must check gauges while performing other tasks.
Protective Measures:	None
Recommendations:	Consider installing pressure transmitter with control room indication and monitoring. Consider installing local high pressure alarm.
Consequence: Possible exposure of furnace operator to explosion.	
Human Factors:	Operator is present at furnace.
Protective Measures:	None
Recommendations:	Consider automating furnace startup.

Figure 6. LOPA-HF Worksheet For Furnace Startup - Scenario 2

LOPA - HUMAN FACTORS WORKSHEET	
Scenario Description: Operator ignites pilot in fire box when LEL is exceeded causing an explosion.	
Initiating event: Operator does not perform LEL check.	
Human Factors:	Operator bypasses LEL test under pressure to start up. Operator forgets due to work overload - operator sometimes has to perform other tasks while starting furnace.
Protective Measures:	Training of operator.
Recommendations:	Consider requiring LEL test to be performed by a different operator. Place additional Warning in furnace startup procedure immediately prior to LEL test step. Ensure furnace operator does not perform other tasks while starting furnace as a matter of policy.
IPL 1: Furnace startup procedure requires LEL testing	
Human Factors:	Test equipment mis-calibrated. Test equipment not used properly.
Protective Measures:	QC program for test equipment. Operator training.
Recommendations:	Consider use of redundant diverse test equipment.
Enabling events: Ignition source/pilots lit	
Human Factors:	Mindset
Protective Measures:	None
Recommendations:	Consider requiring second LEL test by another operator for confirmation.
Consequence: Possible exposure of furnace operator to explosion.	
Human Factors:	Operator is present at furnace.
Protective Measures:	None
Recommendations:	Consider automating furnace startup.

Figure 7. LOPA-HF Worksheet For Furnace Startup - Scenario 3

LOPA - HUMAN FACTORS WORKSHEET	
Scenario Description: Pilots not ignited but fire box is filled with fuel and presents a potential for fire and explosion when fuel finds an ignition source.	
Initiating event: Operator establishes fuel flow without igniting pilots.	
Human Factors:	Work overload - operator sometimes has to perform other tasks while starting furnace. Valve position not indicated on fuel valves.
Protective Measures:	Procedure is written according to best practices. Location of manual fuel supply valve is next to pilot so operator can visually check if it is lit before opening fuel valve.
Recommendations:	Ensure furnace operator does not perform other tasks while starting furnace as a matter of policy. Consider providing fuel valve position indicators.
IPL 1: Automatic trip on fuel flow if no flame detected.	
Human Factors:	Inadequate maintenance of flame detector
Protective Measures:	MI Procedures
Recommendations:	Provide regular refresher training to contract mechanics.
Enabling events: Ignition source	
Human Factors:	None
Protective Measures:	-
Recommendations:	-
Consequence: Possible exposure of furnace operator to fire or explosion.	
Human Factors:	Operator is present at furnace.
Protective Measures:	Fire extinguishers.
Recommendations:	Consider automating furnace startup.