

DEP SPECIFICATION

SAFEGUARDING AND INSTRUMENTED PROTECTIVE FUNCTIONS FOR ROTATING EQUIPMENT

DEP 32.29.20.10-Gen.

February 2011
(DEP Circular 74/11 has been incorporated)
ECCN EAR99

DESIGN AND ENGINEERING PRACTICE

DEM1



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TABLE OF CONTENTS

1.	INTRODUCTION	4
1.1	SCOPE	4
1.2	DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS	4
1.3	DEFINITIONS	4
1.4	CROSS-REFERENCES	5
1.5	SUMMARY OF MAIN CHANGES	6
1.6	COMMENTS ON THIS DEP	6
1.7	DUAL UNITS	6
2.	GENERAL	7
2.1	OBJECTIVES	7
3.	ROTATING EQUIPMENT SAFEGUARDING BACKGROUND	8
3.1	MACHINE ALARM AND SHUTDOWN FUNCTIONS	8
3.2	SHUTDOWN SETTINGS	8
3.3	TIME DELAYS	8
4.	IPF CLASSIFICATION BY MACHINE TYPE	10
4.1	GENERAL	10
4.2	AXIAL AND CENTRIFUGAL COMPRESSORS AND EXPANDERS	11
4.3	RECIPROCATING COMPRESSORS	14
4.4	WET SCREW COMPRESSORS	15
4.5	DRY SCREW COMPRESSORS	15
4.6	SPECIAL PURPOSE STEAM TURBINES	16
4.7	HIGH ENERGY PUMPS (typically unspared)	18
4.8	SEAL SYSTEMS FOR HIGH ENERGY, GENERAL-PURPOSE AND LIQUID RING PUMPS	18
4.9	LARGE ELECTRIC MACHINES (MOTORS, GENERATORS, ALTERNATORS TYPICALLY IN UNSPARED SERVICE)	19
4.10	GEARBOXES	19
4.11	GAS AND DIESEL ENGINES	20
4.12	GAS TURBINES	21
4.13	ALL MACHINES	22
5.	REFERENCES	23

APPENDICES

APPENDIX A	ROTATING EQUIPMENT SAFEGUARDING PHILOSOPHY	24
APPENDIX B	GUIDANCE TABLES FOR SAFETY INTEGRITY LEVEL ASSESSMENT	30

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for safeguarding and Instrumented Protective Functions (IPFs) for rotating equipment. For guidance on condition monitoring of rotating equipment, refer to DEP 31.29.00.11-Gen.

Protecting and safeguarding rotating equipment prevents or limits the possible damage to this equipment in the event of a malfunction. It avoids or significantly limits consequential damage to the environment, minimizes potential hazards for people, prevents damage to adjacent equipment and minimizes significant lost revenue for the facility. This DEP provides functional safeguarding requirements for vital and essential rotating equipment, either spared or non-spared, in continuous operation, but does not provide safeguarding requirements beyond rotating equipment protection. For safeguarding other plant equipment and processes (e.g. reactors, heaters, vessels, etc.) where tripping the rotating equipment is considered critical to the success of the safeguard, there may be additional requirements on the rotating equipment IPF beyond those described herein.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual DEM 1 – Application of Technical Standards.

This is a revision of the DEP dated January 2010; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process should be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions and abbreviations

Alarm	An audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring a response. (ANSI/ISA-18.2) A warning of the presence of a hazard to life, property or the environment. (IEC 60839-1-1)
Essential	A service in which failure of equipment renders a plant inoperable or reduces performance to an unacceptable level.
High Energy Pumps	Pumps with head greater than 200 m (650 ft) per stage and with power more than 225 kW (300 bhp) per stage.
IPF	Instrumented Protective Function
NFPA	National Fire Protection Association (USA)
OEM	Original Equipment Manufacturer
SIL	Safety Integrity Level
SIL Assessment	A team activity whereby the SIL of one or more IPFs is established and the rationale documented using a defined methodology. In the same session related Safety Integrity System requirements are defined and documented. The Shell SIL assessment methodology is defined in DEP 32.80.10.10-gen.
Trip	Automatic shutdown of a machine upon reaching a pre-set trip value.
Pre-alarm	An alarm that, if not responded to, may result in a demand on an IPF i.e. a machine trip.
Process Safety Time	The period of time in which the process can be operated without protection and with a demand present without entering a dangerous condition. The Process Safety Time determines the dynamic response requirements of the IPF.
Vital	A service in which failure of equipment may cause an unsafe condition, resulting in jeopardy to life and/or major damage (fire, explosion etc.).

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (5).

1.5 SUMMARY OF MAIN CHANGES

This is a revision of the DEP dated January 2010. The main, non-editorial changes are as follows:

Old section	New Section	Change
2.1 OBJECTIVES	2.1 OBJECTIVES	Deleted reference to IEC 61508 and IEC 61511
3.2. Shutdown Setting	3.2 Shutdown settings	Removed section regarding start permissives.
6 References	6 References	Removed reference to the following DEPS: • Special-purpose steam turbines (amendments/supplements to ISO 10437) DEP 31.29.60.31-Gen. • Combustion gas turbines (amendments/supplements to API 616) DEP 31.29.70.31-Gen.
Appendices	Appendices	Appendix A and B switched. Appendix B now incorporated into document.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the Administrator at standards@shell.com, using the DEP Feedback Form. The DEP Feedback Form can be found on the main page of "DEPs on the Web", available through the Global Technical Standards web portal <http://www.shell.com/standards> and on the main page of the DEPs DVD-ROM.

1.7 DUAL UNITS

**Amended per
Circular 74/11**

Dual units have been incorporated throughout this DEP.

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

2. GENERAL

2.1 OBJECTIVES

The type of protection to be applied depends largely on the type of rotating equipment. The main strategy for any machinery is to protect against operating the equipment outside its integrity and performance design envelope. For several types of equipment, this protection is defined according to International and API standards, particularly API Std 670.

Also, the IPFs shall be SIL assessed as described in DEP 32.80.10.10-Gen. The underlying presumption is that adequate operational attention is paid to the rotating equipment in service, that correct pre-start checks are carried out prior to putting machines into operation, and that adequate start permissives are in place.

Some rotating equipment packaged units have dedicated safeguarding and control systems included in the package instead of being integrated in the overall plant safeguarding and DCS systems. Typically, gas turbine driver packages are equipped with their own dedicated systems, which often feature the "single start/stop button" design. The package safeguarding and control systems include start permissives, programmed operational logic, and alarm and shutdown functions. For these packages, the safeguarding system should be SIL assessed to assure compliance with IPF classification and implementation methodology. In the absence of IPF classification and/or RCM analysis, the Vendor's instrumentation maintenance and inspection/testing requirements shall be followed.

3. ROTATING EQUIPMENT SAFEGUARDING BACKGROUND

3.1 MACHINE ALARM AND SHUTDOWN FUNCTIONS

Machine safeguarding shutdown functions (“trips”) are required on rotating equipment to prevent serious failures resulting in potential hazards to personnel or the environment and in extended process unit downtime. All machine trips require a pre-alarm prior to a shutdown in order to give Operations a chance to take action to prevent a trip.

The decision to install trip functions shall be based on a SIL Assessment and shall comply with this DEP and take into consideration the recommendations of the Original Equipment Manufacturer (OEM). The IPF methodology applied here is designed to avoid unnecessary machine trips. Appendix B shows the recommended trip voting and instrument redundancy to avoid nuisance trips. In some processes it is safer to keep the machine running in order to carry out an orderly process shutdown. In those cases, the shutdown system should be sequenced to do so automatically so that the process is returned to a safe situation before the machine is shut down.

3.2 SHUTDOWN SETTINGS

There are three main safety/integrity barriers for rotating equipment - process containment, mechanical containment and prevention of ignition sources. Shutdown settings shall be established to protect against major equipment failures that could breach these barriers and lead to a process safety and/or asset integrity incident. Once the shutdown level is reached, the equipment shall shut down automatically.

In some cases trip multipliers may be required for machine startup. In the case of a trip multiplier, the normal setting is multiplied by a factor 2 or even 3 during start-up to prevent a trip during start-up whilst maintaining some protection rather than no protection as would be the case when applying a start-up override. The use of a trip multiplier is exceptional and requires the approval of the principal.

Shutdown settings shall be selected to prevent or minimize major failures, including:

- Loss of containment in the machine through the seals or the main casing / bearing housings.
- Loss of containment from vibration induced fatigue failure of attachments to the machine, which generally occurs first at flanges or on small-bore piping, tubing and instruments.
- Secondary damage to the nearby facilities from failed machine components due to breaching mechanical containment.
- Failures that will keep the machine down for extended periods, e.g. those entailing damage to the casing or stationary components. Bearing and rotor damage may result when a shutdown event occurs.

3.3 TIME DELAYS

Machine trip functions shall not have time delays unless the equipment Vendor can demonstrate that any proposed trip delay will not adversely impact the safeguarding and reliability of the equipment. In all cases, overspeed trip functions, axial position trip functions, surge shutdown on axial compressors and manual trip buttons SHALL [PS] have no time delays in instrument system design to prevent significant equipment damage and plant exposure. All proposed time delays for functions other than those listed above are subject to the Principal's approval.

Typical packaged shutdown PLCs, vibration monitoring systems, surge control systems and other instrument package systems may have built-in time delays as a standard feature usually intended to prevent spurious trips caused by signal noise or fast transients. The default settings from the instrument Vendor will likely include a few seconds of time delays. These shutdown time delay settings shall be reviewed during engineering design, installation, and system commissioning. There are some pieces of equipment where

automatic start-up overrides (time and/or condition limited override during machine start-up) are necessary for equipment start up. Start-up overrides and temporary start-up time delays are subject to the Principal's approval.

Depending on the plant site, time delays on selective trip points may be justified to prevent nuisance trips from rough weather or other factors. In such cases, time delays should not be limited to just rotating equipment. Before adding time delays to machine trip functions, it should be confirmed that the shutdown system design does not already include a system delay in the plant shutdown hardware. If a time delay is found to be necessary, the time delay plus the time to trip SHALL [PS] not exceed the calculated Process Safety Time. These time delays shall be reviewed with and approved by the Principal.

4. IPF CLASSIFICATION BY MACHINE TYPE

4.1 GENERAL

The recommended safeguarding for various types of rotating equipment, along with Safety Integrity Levels for Instrumented Protective Function trips, is shown in the following tables contained in (4.2. through 4.13).

When performing a SIL Assessment for a specific project or piece of equipment, the IPF design shall consider the recommended SIL levels given within the tables. The SIL can only be reduced if determined during a project's SIL Assessment. The instrumentation type, level of redundancy, and voting logic selection shall be based on the SIL according to process safety, plant economics and environmental considerations as determined during the IPF design.

The tables include recommended IPF requirements and selective alarms for the subject equipment. Other trips, alarms, and permissives may be necessary, depending on the particular equipment Manufacturer/Supplier's requirements, recommendations and local needs.

4.2 AXIAL AND CENTRIFUGAL COMPRESSORS AND EXPANDERS

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High KO drum level	SHALL [PS] Trip	SIL 2	Prevents severe damage to compressor internals by liquid carryover leading to extensive downtime and repair and seal failure leading to a gas release.
High discharge temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Discharge temperature could exceed maximum allowable operating temperature, which could lead to failure of sealing components.
High axial displacement	SHALL [PS] Trip	SIL 2	Prevents major damage to the rotor and stationary components if thrust bearing should fail. Where 3 probes are fitted, shutdown shall be 2oo3. All other cases, shutdown shall be 2oo2. Shutdown levels shall be selected to prevent the most serious failures, including loss of containment, rotor replacement or refurbishment, and damage to the casing or stationary components.
High radial vibration	SHALL[PS] Trip	SIL 1/2	Radial vibration shutdown shall always be provided on centrifugal compressors if one or more of the following conditions apply, irrespective of an IPF review: - A compressor suction pressure of more than 200 barg (2,900 psig). - A compressor with an average power density of more than 5 MW (6,705 hp) per impeller. - A remote, not normally manned installation. - An installation where the possibilities for operational intervention to assess and act on vibration alarms in a timely manner are minimal or non-existent. See discussion in Appendix A
Low lube oil header pressure	Shall Trip	SIL 1	Prevents severe damage to compressor from lost oil pressure to bearings, leading to extensive downtime and repairs.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing and/or compressor sealing system failure.
Low overhead seal tank level – oil bushing process seals	SHALL [PS] Trip	SIL 2	For compressors with straight or conical bushing seals, seal oil in the annulus between the bushing and compressor shaft prevents process gas from leaking to the atmosphere. Oil pressure is maintained at a pressure above seal chamber pressure and set by overhead seal tank level. If the seal oil tank level drops below a minimum level, process gas pressure will overcome the oil pressure leading to gas leaks from the seals.
Low differential seal oil pressure – oil contact process seals	SHALL [PS] Trip	SIL 2	For compressors with contact seals, seal oil pressure runs at a pressure higher than the seal chamber to act as a sealing barrier. Seal oil is used to lubricate the rotating and stationary seal faces. Loss of differential pressure between seal oil and process pressure will cause immediate contact of the seal faces leading to a seal failure. Process gas will likely leak to the atmosphere through the outer seal.
Low differential pressure – pressurized double dry gas process seals	SHALL [PS] Trip	SIL 2	Loss of differential pressure across the outer seal face will lower the pressure between the inner seal and the compressor sealing pressure. Reverse pressure on the inner seal face will open it up, allowing process gas to leak through the outer seal to the atmosphere and into the oil system.
High seal gas flow – pressurized double dry gas process seals	Alarm	Layer of Protection	High seal gas flow could indicate that either inner seal or outer seal is leaking excessively. Operator must investigate and take appropriate action to prevent tripping on low differential pressure.

4.2 AXIAL AND CENTRIFUGAL COMPRESSORS AND EXPANDERS (CONTINUED)

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High primary vent flow or high primary vent pressure – tandem dry gas process seals	Alarm or Trip	Layer of Protection to SIL 1	High vent flow indicates the primary seal has failed and the machine is running on the secondary seal. Primary seal failure could potentially lead to a secondary seal failure and loss of containment. Some systems are designed to measure high pressure upstream of a flow orifice which also indicates a failed primary seal. If the trip function is not utilized, the operations alarm shall be a high priority alarm demanding immediate well-defined attention. The machine shall be shut down in a controlled fashion to minimize process system upsets and/or excessive flaring.
Low secondary seal gas supply pressure – tandem dry gas process seals	Alarm	Layer of Protection to SIL 1	Low secondary seal gas pressure could indicate a loss of intermediate gas pressure that is used to sweep primary seal leakage to the primary vent. It may also indicate a loss of the secondary seal or the internal seal labyrinth has failed. Secondary seal gas pressure can be measured upstream of the internal labyrinth on the dry gas seal panel or in the vent line upstream of the flow orifice. A failed secondary seal could lead to a primary seal failure and loss of containment. Loss of intermediate gas pressure should be a high priority alarm that requires Operations to immediately investigate and re-establish gas supply. If supply pressure is lost, the condition of the secondary seal is unknown and should be assume to have failed until re-establishment of the supply confirm the seal is in good condition. After supply pressure has been re-established, good secondary seal condition can be confirmed by low flow to the secondary vent and normal pressures in the primary vent.
High secondary vent flow or high secondary vent pressure – tandem dry gas process seals	Alarm or Trip	Layer of Protection to SIL 1	High secondary seal vent flow could indicate the secondary seal has failed or it could indicate the separation seal has failed. Secondary seal vent flow should be measured on each vent line from the compressor seal cavities and must be routed to a safe location. During a secondary seal failure, intermediate gas and primary seal gas leakage will likely vent through the secondary seal vent. A failed secondary seal could potentially lead to a primary seal failure and loss of containment. Some systems are designed to measure high pressure upstream of a flow orifice in the secondary vent line. If the trip function is not utilized, the operations alarm shall be a high priority alarm demanding immediate well-defined attention. The machine shall be shut down in a controlled fashion to minimize process system upsets and/or excessive flaring.
High primary vent flow or high primary vent pressure – tandem dry gas process seals PLUS High secondary vent flow or high secondary vent pressure – tandem process dry gas seals	SHALL [PS] Trip	SIL2	If both the primary and secondary vents have high flow or if there is high pressures upstream of their orifices, this is an indication of failure of both dry gas seals. Failure of the primary and secondary seals shall trip the compressor.

4.2 AXIAL AND CENTRIFUGAL COMPRESSORS AND EXPANDERS (CONTINUED)

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
Low seal gas differential pressure or low flow to the seal – all process dry gas seal types	Alarm	SIL 1	Seal gas pressure or adequate seal gas flow is required prior to starting equipment to assure a positive flow of clean gas around the dry gas seal and across the internal process labyrinths into the compressor. This clean gas protects the primary dry gas seal from any process debris in the casing that might damage the seal during early and continuous operations. This shall also be a permissive to start.
Low separation gas pressure – all process dry gas seals	Alarm	Layer of Protection	This shall be a permissive to start lube oil pump(s). Without separation gas flow, oil will likely migrate into the dry gas seals.
Surge	Centrifugal compressor Alarm or trip Axial compressor SHALL [PS] trip.	Layer of protection – SIL 2 for Axial compressor	Surge control system shall be provided to minimize the likelihood of equipment surges during start up, operations and shutdown, and is the primary protection against surge events. The surge trip function is a backup if the surge control system fails. Because of their design, axial compressors shall be tripped on excessive surge events as defined by the compressor Manufacturer/Supplier. For many centrifugal compressors, an alarm may be all that is necessary. However, there are some sizes of centrifugal compressor where surge trips are recommended. This depends on power density, pressure levels, process gas, and plant economics. If the surge controller or process pressure, flow and temperature input instruments should fail, the surge controller should be designed with backup default condition. Generally, an alarm will sound and the surge control valve will hold its last position. The operator can then operate the valve manually to protect the compressor.
Expander Overspeed	SHALL [PS] Trip	SIL 2	Expanders like turbines can experience severe machine damage resulting in a breach of process containment or mechanical containment in the event of an overspeed. Hot gas expanders are often part of a Power Recovery Compressor Train in an FCCU and, as such, shall be subject to the same requirements as the compressor and other drivers in the train. If they are in a separate power recovery configuration, they shall also follow the same requirements as set for the main compressor equipment in the plant. In both train configurations, the hot gas expander turbine shall have independent overspeed trip protection similar to steam and gas turbines. Expanders shall be equipped with an overspeed protection system that is independent of other control systems. The equipment OEM shall describe the overspeed design criteria and protection philosophy (including test facilities up to the expander inlet valve). The required system speed of response shall be determined. The overspeed system shall respond within these limits to prevent damage to the equipment rotor and potential loss of containment. A two out of three (2oo3) voting logic shall be applied on electronic overspeed detection systems unless indicated otherwise by the IPF and SIL Assessment. Time delays are not allowed on any overspeed trip protection systems.
NOTE: Dry gas seals instrumentation shall be selected from the above options and agreed with OEM. The alarms and trips shall be selected with the objective to assure safe, reliable failure detection for both the inner and outer dry gas seals.			

4.3 RECIPROCATING COMPRESSORS

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High KO drum level / gas scrubber level	SHALL [PS] Trip	SIL 2	Prevents severe compressor damage by liquid carryover leading to extensive downtime and repairs, rod failure and or cylinder failure resulting in a significant process release.
High discharge temperature	Trip	SIL 1	High compression ratio, high suction temperature, changing process gas types can all cause elevated discharge temperatures. Excessive discharge temperatures could lead to failure of any non-metallic parts and components.
Valve temperature	Alarm	Layer of Protection	High valve cover temperatures are an indication of poor compressor valve performance and/or failure. Poor valve performance leads to lost compressor capacity and potentially to poor reliability of other mechanical components. Best valve temp measurement is in a thermowell in the valve cover or cylinder near the valve so the measurement is close to the valve.
Frame vibration	SHALL [PS] Trip	SIL 2	Vibration trip levels are set to prevent major failures that could lead to major machine damage. Voting velometers at the same location (2oo2) are to be provided if required to meet availability upon demand criteria for a SIL 2. For long frame machines (more than 6 cylinders), frame transducers at each main bearing are recommended. In general frame transducers at each end of the machine are sufficient.
Crosshead vibration	SHALL [PS] Trip	SIL 1/ 2	Vibration trip levels are set to prevent major failures that could lead to loss of containment particularly broken piston rods or loose piston nuts. Voting accelerometers at the same location (2oo2) will typically be required to meet availability upon demand for SIL 2.
When provided: bearing temperature (temperature sensors for main bearings, crosshead pins, etc.)	Alarm/Trip	Layer of Protection	Alarm on bearing temperatures is minimum requirement. Some machines and facilities may require bearing temperature trip.
Low frame oil pressure	SHALL [PS] Trip	SIL 2	Prevents severe damage to compressor from lost oil pressure to bearings resulting in piston rod failure and breach of process containment.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing and/or compressor sealing system failure.
When provided: Rod drop	Alarm	Layer of Protection	There may be cases (such as non lubed cylinders) where rod drop should be a trip. Alarms should be on both position and dynamic deflection (rod vibration).
Cylinder differential pressure or low suction pressure	Alarm/Trip	SIL 1	Some compressors require protection from low suction pressure operation. Others may require protection from very high differential pressure to prevent allowable rod loads and/or frame ratings from being exceeded. For those machines, trip function should be provided.
Discharge pressure	Alarm / Unload compressor	Layer of Protection	Discharge pressure protection can be provided to prevent venting process unit pressure through a relief device to the flare. SIL Assessment should be based on site environmental regulations.
Cylinder lubricator low pressure, flow, or level.	Alarm	SIL 1	Lubricator should be running before the main driver is started. After the main driver is shut down, the lubricator should also be shut down automatically to prevent the cylinders from filling with lubricant. Permissive to start and automatic shutdown of lubricator when machine is shutdown or tripped.

4.4 WET SCREW COMPRESSORS

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
Casing accelerometer	Alarm	Layer of Protection	Casing accelerometers are used to monitor the overall casing vibrations levels.
High axial displacement	SHALL [PS] Trip	SIL 2	Some compressors are designed to allow for monitoring of the axial movement of the rotors. If this capability exists, excessive axial displacement should be set to trip. Where 3 probes are fitted, shutdown shall be 2oo3. In all other cases, shutdown shall be 2oo2.
Low lube oil header pressure	Shall Trip	SIL 1	Prevents severe damage to compressor from lost oil pressure to bearings, leading to extensive downtime and repairs.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing and/or compressor sealing system failure.
Low sealing differential oil pressure	SHALL [PS] Trip	SIL 2	Circulating oil is used to seal between the compressor rotor and the casing. Circulating oil shall operate at a pressure higher than the compressor discharge pressure. If the circulating oil pressure is too low, gas will be recirculated internally within the compressor casing. Circulating oil is also used to lubricate the compressor shaft seals.
High discharge pressure	Alarm or Trip	Layer of Protection or SIL1	Discharge pressure protection can be provided to prevent venting process unit pressure through a relief device to the flare. SIL Assessment should be based on site environmental regulations.

4.5 DRY SCREW COMPRESSORS

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
Casing accelerometer	Alarm	Layer of Protection	Casing accelerometers are used to monitor the overall casing vibrations levels.
High axial displacement	SHALL [PS] Trip	SIL 2	Some compressors are designed to allow for monitoring of the axial movement of the rotors. If this capability exists, excessive axial displacement should be set to trip. Where 3 probes are fitted, shutdown shall be 2oo3. In all other cases, shutdown shall be 2oo2.
Low lube oil header pressure	Shall Trip	SIL 1	Prevents severe damage to compressor from lost oil pressure to bearings leading to extensive downtime and repairs.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing and/or compressor sealing system failure.
High discharge pressure	Alarm or Trip	Layer of Protection or SIL1	Discharge pressure protection can be provided to prevent venting process unit pressure through a relief device to the flare. SIL Assessment should be based on site environmental regulations.

4.6 SPECIAL PURPOSE STEAM TURBINES

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High axial displacement	SHALL [PS] Trip	SIL 2	Prevents major damage to the rotor and stationary components that can result in blade or disk failure and release of mechanical energy. For steam turbines, the turbine shall be on axial position. Where 3 probes are fitted, shutdown shall be 2oo3. In all other cases, shutdown shall be 2oo2.
High radial vibration	SHALL [PS] Trip	SIL 1/2	Prevents release of mechanical energy in case of blade or disk failure. See discussion in Appendix A
Low lube oil header pressure	Shall Trip	SIL 1	Prevents severe damage to steam turbine from lost oil pressure to bearings, leading to extensive downtime and repairs. For turbines with turning gear, the turning gear operation shall be tripped on low lube oil header pressure.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing failure.
Low lube oil run-down tank level	Alarm	Layer of Protection	Permissive to start turbine on high level to assure there is adequate oil in the event of an emergency trip.
Low governor oil pressure	Alarm Only		Low governor pressure could lead to poor speed control. Additionally a hydraulically operated trip, and throttle valve is typically held open by governor oil pressure. Low pressure could lead to a turbine trip. If the trip valve closes due to low pressure, the process system IPF needs to know the machine has tripped.
High exhaust hood temperature (condensing turbine)	Alarm	Layer of Protection	For condensing turbines, excessive exhaust hood temperature could lead to turbine blade failure when operated at full speed. A trip should be considered if the maximum allowable working temperature can be exceeded for extended periods during start-up.
Surface condenser vacuum	Alarm – high pressure Alarm – Low vacuum	Layer of Protection	For locations where the cooling water can get very cold, the vacuum can be pulled lower than the turbine's design capabilities. A low vacuum alarm should be considered. Note: During overspeed, high vibration, high axial displacement and low lube oil pressure IPF trip, the vacuum should be broken by opening a valve within the surface condenser quickly to stop the turbine.
High surface condenser level	SHALL [PS] Trip	SIL 2	Depending on the turbine exhaust configuration, condensed liquid may be able to reach the turbine blading resulting in blade failure. In these cases, a trip is required. Within the surface condenser, the high level alarm shall be set as low as possible to give Operations adequate time to respond to the alarm and correct the problem prior to a high level trip.
Low extraction pressure	Shall Trip	SIL 1	Depending on machine design, a low extraction pressure trip may be necessary to protect turbine blading.

4.6 SPECIAL PURPOSE STEAM TURBINES (CONTINUED)

Overspeed	SHALL [PS] Trip	SIL 2	SIL assessment for compressors should consider coupling failures. SIL assessment for generators should consider loss of electrical load. Failure from overspeed could lead to a major wreck of the turbine. SIL level is calculated based on a fully redundant speed control system, including controllers, position feedback transmitters and speed pick-ups. Steam turbine drivers shall be equipped with an overspeed protection system that is independent of other control systems. The equipment OEM shall describe the overspeed design criteria and protection philosophy (including test facilities up to the main steam trip valve). The required system speed of response shall be determined. The overspeed system shall respond within these limits to prevent damage to the equipment rotor and potential loss of containment. A two out of three (2oo3) voting logic shall be applied on electronic overspeed detection systems unless indicated otherwise by the IPF and SIL Assessment. Time delays are not allowed on any overspeed trip protection systems.
Low speed alarm	Alarm only		If the speed control system should fail, or during upset (very low inlet steam pressure) conditions, the turbine could slow down to below minimum operating speed. This alarm will alert the operator to trip the turbine to prevent running the machine train at lateral critical speeds.
Slowroll speed alarm	Alarm only		For turbines with turning gears, this alarm alerts the operator that the turbine rotor is no longer turning at the very low speeds.
Loss of speed probes	SHALL [PS] Trip	SIL2	Upon failure of all governor speed probes, the turbine shall be shut down to prevent overspeed event and release of mechanical energy
NOTE When turbines are used to drive other rotating equipment, the turbine trip systems are critical to provide the mechanical protection of all the equipment in the train, as well as any other process safeguarding IPFs that depend on tripping the turbine. Therefore, the turbine trip system shall meet the required SIL of the IPF with the highest SIL requirement. As a minimum, the turbine shall be provided with a trip system that dumps governor oil pressure from both the trip and throttle valve (TTV) and the governor speed control valve. The steam turbine trip system shall force the governor valves closed in addition to tripping the trip valve(s). With this approach, redundant steam trip valves are not required to meet IPF requirements.			

4.7 HIGH ENERGY PUMPS (typically unspared)

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High axial displacement	SHALL [PS] Trip	SIL 2	Prevents major damage to the rotor and stationary components. Where 3 probes are fitted, shutdown shall be 2oo3. In all other cases, shutdown shall be 2oo2.
High radial vibration	SHALL [PS] Trip	SIL 1 /2	See discussion in Appendix A.
High radial casing vibration	Alarm or Trip	Layer of protection to SIL 1	For high-pressure high-energy waterflood pumps, casing vibration has proven to be an appropriate measurement to supplement the proximity probes.
Casing temperature	Permissive to start on high temperature pumps	SIL 1	For multistage pumps that operate at high elevated temperatures, the casing and internals need to be warmed up evenly and at a defined rate prior to starting to prevent internal contact of the rotor with the stationary components. For pumps at ambient temperature, casing temperature monitoring is not required.
Low flow	Trip	SIL 1	High-pressure pumps shall always operate above their minimum flow. Operating a low flow could lead to pump damage and potential seal failure from cavitation, flow instability leading to high vibration, overheating, operating at deadhead, etc.
Low lube oil header pressure	ShallTrip	SIL 2	High-energy pumps will likely have independent lube oil systems. Prevents severe damage to pump from lost oil pressure to bearings, leading to extensive downtime and repairs.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing failure.

4.8 SEAL SYSTEMS FOR HIGH ENERGY, GENERAL-PURPOSE AND LIQUID RING PUMPS

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
Seal pot high and low level – Pressurized (ISO 21049, Seal flush Plan 52 or 53A)	Alarm or Trip	Layer of Protection to SIL 2	For light hydrocarbon pump services, IPF low and high liquid level trips should be evaluated for Seal Flush Plan 52 and 53A. For other process services, operator attention may be all that is necessary.
Barrier Gas Pressure for API Plans 53B, 53C, and 54	Alarm or Trip	Layer of Protection to SIL 2	Loss of barrier gas pressure could lead to loss of containment for the pump seal, resulting in a release.
Dry gas seal barrier gas system	Alarm or Trip	Layer of Protection to SIL 2	Loss of barrier nitrogen could lead to a release of pump fluid. IFP requirement depends on the process service.
Seal failure detection on toxic, flammable and high energy pumps	SHALL [PS] Trip	SIL 2	There may be several alternative approaches to seal failure detection depending on pump and seal plan.
NOTE: Typically, centrifugal pump installations do not require overpressure protection because the piping system is rated higher than the pump's blocked in pressure. If not, relief protection is required.			

4.9 LARGE ELECTRIC MACHINES (MOTORS, GENERATORS, ALTERNATORS TYPICALLY IN UNSPARED SERVICE)

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High radial vibration	Shall Trip	SIL 1	Vibration trip function on radial vibration is generally only required on motors driving equipment that is equipped with radial proximity probes. Vibration trip levels are set to prevent major failures that could lead to rotor to stator contact. They are not designed to prevent bearing damage. When applied, shutdown shall be 2oo4 probes. See discussion in Appendix A.
Low lube oil header pressure	Shall Trip	SIL 2	Large motors are part of the vital or essential equipment train with an integrated lube oil system. The SIL for the driven equipment determines the SIL for the motor driver. SIL1 may be considered if the motor is not driving a vital or essential piece of equipment.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing failure.
Motor winding temperature	Alarm/trip	Layer of Protection	Some machines and facilities may require motor winding temperature trips.
NOTE: A large motor is defined as an electrical motor built to API Std 541 or API Std 546 or IEC 60034-1.			

4.10 GEARBOXES

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High axial displacement	Shall Trip	SIL 1	Some double helical gears do not have thrust bearings; however, gears with thrust bearings shall include axial displacement trips to prevent major damage to the gears and gear case. Where 3 probes are fitted, shutdown shall be 2oo3. In all other cases, shutdown shall be 2oo2.
High radial vibration	Shall Trip	SIL 1	Vibration trip levels are set to prevent major failures that could lead to loss of containment. They are not designed to prevent bearing or internal damage. If applied, shutdown shall be 2oo4 probes (on each gear shaft). During the start up period, pinion displacement vibration may exceed the trip settings. In this case a 3X multiplier should be applied to the shutdown level to automatically increase set points on the gearbox during start up. Once the compressor reaches operating speed, the multiplier shall be deactivated. See discussion in Appendix A.
Casing accelerometer	Alarm	Layer of Protection	Casing Accelerometer. This is added mainly for condition monitoring purposes. Used to detect gear meshing defects and teeth defects.

4.11 GAS AND DIESEL ENGINES

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
Frame vibration	Alarm or trip	Layer of Protection to SIL 1	Generally, an accelerometer is applied on the frame below the cylinders on each end of the machine.
Inlet air differential pressure	Alarm or trip	Layer of Protection to SIL 1	Differential pressure indication for air filter plugging.
Low lube oil pressure	SHALL [PS] Trip	SIL 1 or 2	The SIL for the driven equipment determines the SIL for the engine. SIL1 may be considered if the driver is not driving a vital or essential piece of equipment. Loss of lube oil to an engine can result in severe engine damage and release of mechanical energy (thrown piston rod crank failure etc).
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. High lube oil temp can lead to bearing, tappet and piston failure.
High engine coolant temperature	Shall Trip	SIL 1	Prevents the engine from overheating.
Low fuel gas pressure	Shall Trip	SIL 1	
Overspeed	SHALL [PS] Trip	SIL 2	SIL Assessment for overspeed should be done for coupled and uncoupled cases. Failure from overspeed could lead to a major wreck. Gas and diesel engines shall be equipped with an overspeed protection system that is independent of other control systems. The equipment OEM shall describe the overspeed design criteria and protection philosophy (including test facilities up to the fuel gas trip valve). The required system speed of response shall be determined. The overspeed system shall respond within these limits to prevent damage to the equipment. A two out of three (2oo3) voting logic shall be applied on electronic overspeed detection systems unless indicated otherwise by the IPF and SIL Assessment.
NOTE: For NFPA requirements for engines driving firewater pumps, the only trip functions shall be limited to Overspeed and Manual Trips.			

4.12 GAS TURBINES

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
High combustor spread temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 should be considered.
High axial displacement	Alarm or SHALL [PS] Trip in case of design with internal pressure balancing	SIL1/SIL 2	Prevents major damage to the rotor and stationary components. For gas turbine with internal pressure balancing, gas turbines shall trip on axial position. Where 3 probes are fitted, shutdown shall be 2oo3. In all other cases, shutdown shall be 2oo2. For gas turbines without internal pressure balancing, axial position shutdown are not recommended unless required by the gas turbine vendor.
High radial vibration	SHALL [PS] Trip	SIL 1/2	Vibration may be monitored by either casing accelerometers or proximity probes as appropriate to the machine design. Vibration trip levels are set to prevent major failures that could lead to loss of containment or collateral damage. They are not designed to prevent bearing or internal damage. When proximity probes are used for monitoring and shutdown, the shutdown shall be 1oo2 or 2oo4. Gas Turbine drives may experience high vibration levels during start up. During this start up period, it is likely the casing vibration will exceed the trip settings. A 3X multiplier shall be applied to the shutdown level to automatically increase set points on the gas turbine during start up when required. Once the turbine is fully up to speed, the multiplier shall be deactivated. See discussion in Appendix A.
Low lube oil header pressure	Shall Trip	SIL 2	Prevents severe damage to gas turbine from lost oil pressure to bearings, leading to extensive downtime and repairs.
High lube oil supply temperature	Alarm or Trip	SIL 1	Alarm assumes machine operating window and appropriate operator actions are defined. Otherwise, a trip and SIL1 shall be provided. Excess oil temperature could lead to bearing failure.
Overspeed	SHALL [PS] Trip	SIL 2	SIL assessment for compressors should consider coupling failures. SIL assessment for generators should consider loss of electrical load. Failure from overspeed could lead to a major wreck of the gas turbine. SIL level is calculated based on a fully redundant speed control system, including controllers and speed pick-ups. Multiple shaft turbines shall have individual overspeed protection for each shaft. Gas turbines shall be equipped with an overspeed protection system that is independent of other control systems. The equipment OEM shall describe the overspeed design criteria and protection philosophy (including test facilities up to the fuel gas trip valve). The required system speed of response shall be determined. The overspeed system shall respond within these limits to prevent damage to the equipment rotor and potential loss of containment. A two out of three (2oo3) voting logic should be applied on electronic overspeed detection systems unless indicated otherwise by the IPF and SIL Assessment. Some gas turbine overspeed systems use a 1oo3 which meets SIL 2 availability upon demand, but increases the risk of false trips. Time delays are not allowed on any overspeed trip protection systems.
NOTE: For a gas turbine driven compressor train, the gas turbine OEM typically provides the shutdowns turbine control panel (TCP). The gas turbine Manufacturer's consent and agreement should be obtained prior to modifying to alarm and trip settings in order to comply with this DEP.			

4.13 ALL MACHINES

Machine Parameter	Alarm or Trip	Recommended IPF Classification	Remarks
Manual Trip	SHALL PS Trip	SIL 2	Manual trips shall be in three places. Typically, they are located near the machine, the base of the stairs at the machine deck and inside the control room.
Bearing temperature, thrust and radial	Alarm/trip	Layer of Protection	Alarm on bearing temperatures is minimum requirement. Some machines and facilities may require bearing temperature trip.

5. REFERENCES

In this DEP, reference is made to the following publications:

- NOTES:
1. Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.
 2. The DEPs and most referenced external standards are available to Shell staff on the SWW (Shell Wide Web) at <http://sww.shell.com/standards/>.

SHELL STANDARDS

Condition monitoring and safeguarding of rotating equipment	DEP 31.29.00.11-Gen.
Classification and implementation of instrumented protective functions	DEP 32.80.10.10-Gen.

AMERICAN STANDARDS

Form-wound squirrel-cage induction motors – 500 Horsepower and larger	API Std 541
Brushless synchronous machines – 500 kVA and larger	API Std 546
Machinery protection systems	API Std 670

Issued by:
American Petroleum Institute
Publications and Distribution Section
1220 L Street Northwest
Washington DC 20005
USA

INTERNATIONAL STANDARDS

Rotating electrical machines – Part 1: Rating and performance	IEC 60034-1
Functional safety of electrical/electronic/programmable electronic safety-related systems	IEC 61508
Functional safety – Safety instrumented systems for the process industry sector	IEC 61511

Issued by:
Central Office of the IEC
3, Rue de Varembe
CH 1211 Geneva 20
Switzerland

Copies can also be obtained from national standards organizations.

Pumps – Shaft sealing systems for centrifugal and rotary pumps	ISO 21049
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Issued by:
ISO Central Secretariat
1, ch. de la Voie-Creuse
Case postale 56
CH-1211 Genève 20
Switzerland

Copies can also be obtained from national standards organizations.

APPENDIX A ROTATING EQUIPMENT SAFEGUARDING PHILOSOPHY

Machine trip functions shall be applied if there is insufficient time and/or opportunity for an operator to take corrective action to prevent a failure and consequential damage. Machine alarms alert the operators that a measured parameter is exceeding its value, indicating that corrective action is required. If this action does not restore acceptable conditions, operators can then initiate a manual shutdown before the equipment is shut down by the trip function.

A1.0 RADIAL VIBRATION SHUTDOWN AND LIMIT SETTINGS**A1.1 General**

Vital and essential rotating equipment shall be provided with vibration measuring devices to monitor the condition of the equipment. Depending on the equipment type, these devices may be either non-contacting probes to monitor shaft displacement or velocity/acceleration transducers to monitor casing/bearing housing movement. In both cases, machine vibration data can be monitored continuously on-line. When a limit is reached, current vibration data and vibration trends can be evaluated so that operational adjustments can be made to reduce vibration levels or a plan can be developed to shut down the equipment for required maintenance. For certain types of failure, vibration levels can increase faster than operators can respond; therefore, automatic shutdown trips are required to protect against loss of containment and major machine damage.

For centrifugal machines, radial vibration probes in X-Y arrangement at each bearing and axial displacement probes shall be configured for automatic shutdown. The shutdown configurations are voting to assure high shutdown availability while minimizing the possibility of nuisance false trips. For radial vibration, the machine should be set up to shut down when the X-Y probes at bearings vote together in a 2oo4 arrangement. The 2oo4 configuration provides protection if either end of the machine manifests a high vibration, and covers the possibility plus recognizes that one plane of vibration malfunction (such as a strongly linear response in the horizontal direction due to support asymmetry) may exceed the danger level, which puts one of the X or Y probes above trip levels. If this happens on both ends of the machine, it is a vote to trip. Historically, experience has shown that if only one of the four probes on the machine shows a high level, it is typically a probe malfunction, and should not actuate a trip signal. The other shutdown configurations are 1oo2, 2oo2 and 1oo4. 2oo2 configuration provides a level of protection from nuisance trips in the event of a probe failure while still providing a high level of protection for the equipment. 1oo4 provides the highest level of protection, but has the highest likelihood of false shutdowns. 1oo2 has become a standard for some OEMs, and provides acceptable availability upon demand for SIL 2, but poses a risk of false trips. Fault tolerance of the system should be evaluated prior to selecting 1oo2 or 1oo4 voting.

A1.2 Radial shaft displacement – General alarm set points

Vibration alarm set points shall be based on one or more of the following methods:

- Historical vibration data with the equipment operating well
- Test stand mechanical run data
- OEM recommendation
- Allowable amplitude, A

Amended per
Circular 74/11

SI units	USC units
$A = 25.4 \sqrt{\frac{12000}{n}}$	$A = \sqrt{\frac{12000}{n}}$
A is the allowable amplitude (unfiltered peak to peak), in μm .	A is the allowable amplitude (unfiltered peak to peak), in mil.
n is the maximum continuous speed, in rpm	n is the maximum continuous speed, in rpm

Alarm set points shall be set sufficiently high above the normal operating point so that they are activated infrequently and indicate an unusual or changing condition, yet at the same time they shall be low enough to provide an early warning so that there is sufficient time to take corrective action to lower the current vibration levels. Depending on the machine type, some machines have two levels of alarm settings to ensure the operator has adequate time to take corrective action. Set points should be mutually agreed with the OEM.

A1.3 Radial shaft displacement – General shutdown set points

As the default, radial vibration shutdowns shall be voted in a 2oo4 configuration (as described in B 1.1). However, during SIL Assessment, other voting configurations can be evaluated and applied if they meet the site's IPF risk tolerance. Radial shutdown levels shall be based on the following criteria:

- Rotor dynamic behavior of the bearing / rotor system.
- Impact on the process system in which the machine operates.

An understanding of a machine's rotor dynamic behavior is required to properly set the shutdown set point level. The machine's rotor dynamic characteristics will determine the vibration level as measured at the probes and bearings that will cause damage from contact with internal casing or stationary machine components. If allowed to continue, vibration levels will increase and intensify. Shutdown vibration limits shall be set below the predicted vibration levels where extensive internal radial rubbing may lead to loss of containment.

Shutdown vibration limit settings shall also take account of the process system in which the machine is operating. For this reason, operating personnel shall start taking corrective action early to lower the machine vibration or take steps to shut down the machine in an orderly fashion. Setting the vibration shutdown limit so the machine trips too early can cause physical or economic damage to other parts of the process system. Nevertheless, shutting down a machine at a high radial vibration level is the machine's last line of defense against loss of containment.

Shutdown vibration limits shall be set after evaluating the machine's rotor dynamic characteristics and impact on the process system. As a general rule for machines in process systems that are more tolerant of machine trips (e.g. an offshore export compressor), a shutdown vibration level of no more than 75 % of bearing clearance shall be used. For a machine where a sudden trip can cause a significant flaring event or significant process damage (i.e. catalyst poisoning), then a shutdown vibration level of 100 % of bearing clearance shall be set. This higher level gives operators every possible opportunity to conduct an orderly shutdown that prevents process system damage, environmental damage and/or loss of machine integrity, which is the purpose of a radial shutdown.