SAMPLE CHECKLISTS

FOR

HAZOPS

AND

SAFETY REVIEWS

SAMPLE HAZOP CHECKLIST

GENERAL

1. Assess Consequences of a Tube Leak

- Pressure (where HP side DP exceeds 1.5 LP side DP)
- Temperature (including auto-refrigeration)
- Chemical reaction
  - overpressure
  - overtemperature
  - formation of solids
- Is pressure relief path adequate and open?
- Other consequences of
  - Leakage of toxics/flammables to
  - undesirable location
  - corrosion, embrittlement or similar effect
- Where double-pipe HP-to-LP differential $\geq$ 70 Bar

2. Can Design Pressures be Exceeded?

- Maximum pressure source – upstream of downstream
- Pressure drop between reboiler and PR valve
- Path of escape or relief adequate and open?
- Adequacy of sizing of PR valve
  - External fire contingency include for reboiler of >5m^3 liquid
- Shutoff against maximum pressure source
  - upstream, downstream, thermal expansion (trapped cold side)
- Can vacuum be created?

3. Can Design Temperatures be Exceeded?

- Maximum upstream temperature at source
- Bypassing of upstream heat removal equipment
- Loss of flow on cold side

4. Loss of Level

- Blow-through of vapour to next vessel (kettle-type boilers only)

5. Is Temperature too High for Downstream Tank?

- THA in rundown line to warn of loss of cooling?

PUMPS

Centrifugal

1. Can Casing Design Pressure be Exceeded?
   - Maximum suction pressure +shutoff delta P
     - Note: If pump curve not available, shut-off delta P (motor drive) may be estimated as 120% of operating delta P and shutoff delta P (turbine-drive) may be estimated as 132% of operating delta P.

   - Higher than design specific gravity of pumped fluid
     - during startup
     - during upsets

2. Is Downstream Piping/Equipment Adequately Rated?

   - If downstream blockage raises suction pressure:
     DP = maximum suction P + shutoff delta P

   - If downstream blockage does not raise suction pressure:
     DP = the greater of:
     Normal suction plus shutoff delta P
     Or
     Maximum suction plus normal delta P

3. Is Backflow Prevented?

   - Check valve in discharge
   - Double check valve for delta P > 70 Bar

4. Suction Piping Overpressure (single pumps)

   - Suction valve, flange and connecting piping same DP as suction line DP.

5. Suction Piping Overpressure (parallel pumps)

   - Suction valve and intervening component DP>3/4 pump discharge DP.

6. Is Damage from Low Flow Prevented?

   - Recycle system to ensure 20% best-efficiency-point flow.

7. Can Fire be Limited?

   - Provide isolation valve(s) if suction vessel(s0) inventory is:
     - light ends > 2000 gallons, or

- HC liquid above $600^{o}F > 10m^3$
- HC liquid > 20 m^3

- Remote actuated if
  - 250mm or large line size, or
  - located in fire risk area (<8m horizontal)
    Note: Valve activator and exposed cable fireproofed.

Positive Displacement

1. Can Casing Design Pressure be Exceeded?

   - PRV in discharge.
   - Set pressure = casing DP minus maximum suction P.
   - PRV discharge location (viscous materials).

CENTRIFUGAL COMPRESSORS

1. Can Design Pressure(s) be exceeded (any component)?

   - Backflow due to trip-out. Minimum DP must be suitable for settling pressure.

   - Backflow via recycle loop
     - Check valves to protect against backflow from downstream
     - Restriction to limit recycle flow and safety valve protection of low pressure stages sized for maximum recycle.

   - Abnormally high molecular weight.

   - Overspeed.

2. Can Design Temperature be exceeded?

   - Too little flow (surge)
     - Blocked outlet
     - High downstream pressure
     - Too low molecular weight

   - Loss of Cooling
     - Upstream
     - Interstage

3. Is there other change of mechanical damage?

   - Liquid carryover
     - Adequate suction KO drum w/alarms, cutouts?
     - Is traced suction line required?

- Surge
  - Adequate automatic recycle?
  - Recycle inside RBV's.

- Reverse rotation
  - Check valves each stage discharge?

- Air entry into machine
  - Can abnormal conditions permit vacuum?
  - If so, is system designed to accommodate?

- Excessive Speed
  - Is overspeed cut-out provided?

4. Can fire be limited?

   - Remote shutdown if >150kw.

   - Isolation valves
     - Total liquid holdup in KO drums <5m^3 or removable in 10 minutes:- suction, discharge and recycle RBV's required.
     - Total liquid holdup >5m^3 not removable in 10 minutes:- individual RBV's in each stage required.

5. Consideration for SV(s)

   - Blocked discharge @ maximum suction pressure.

   - Loss of Cooling.

   - Overspeed – to 105% design or at trip on turbine drives.

   - Molecular weight above design.

POSITIVE DISPLACEMENT COMPRESSORS

1. Can design pressure(s) be exceeded (any component)?
   - Backflow through recycle loop
     - SV's for low pressure stages sized for maximum recycle
     - Consideration of parallel machines
     - Restriction to limit recycle flow – high pressure machines.

   - Shutoff condition in discharge (SV usually required).

2. Can design temperature be exceeded?

   - Loss of Cooling

- Feed or recycle gas
- Cylinder jacket

- Running on total recycle (uncooled).

- Consider exothermix decomposition of compressed fluid.

3. Is there chance of mechanical damage?

- Liquid carryover
  - Adequate suction KO drum.
  - Traced suction line.

- Air entry into machine
  - Can abnormal conditions permit vacuum?
    If so, is system designed to accommodate?

4. Can fire be limited?

- Remote shutdown if >150kw.

- Isolation Valves
  - Total holdup in KO drums < $5m^3$ or removable in 10 minutes:- suction, discharge and recycle RBV's required.
  - Total liquid hold > $5m^3$ not removable in 10 minutes:- Individual RBV's in each stage required.

CONTROL VALVES (Cvs)

- On failure of control medium or signal, does the CV fail in a way to:
  - reduce heat input (cut firing, reboiling, etc)?
  - increase heat removal (increases reflux, quench, perhaps feed, etc)?
  - maintain or increase furnace tube flow?
  - assure adequate flow at compressors or pumps?
  - reduce or stop input of reactant?
  - reduce or stop makeup to a recirculating system
  - bottle the unit in?
  - avoid overpressuring upstream or downstream equipment?
  - avoid overcooling (below minimum desired temperature)?

- Upon plant-wide or single CV failure of control medium or signal, are conflicts among the above-listed objectives satisfactorily resolved?

- Is there provision in the design for failure at a single CV in which the valve either
  - sticks in the opposite from the design failure position, or, where applicable,

- sticks in the single other position which is considered most undesirable?
- fails open with bypass 50% open?

- Will any mode of CV failure result in overpressuring or other risk to equipment or piping, downstream or upstream?
  For example:
  - are upstream vessels between a source of pressure and the CV designed for the maximum pressure when the CV closes?
  - where piping class decreases after the CV, is the piping suitable for the CV wide open with downstream block closed? What about vessels or other equipment in the same circuit?
  - is there any equipment whose material selection makes it subject to rapid deterioration or failure on any specific maloperation or failure of the CV (overheating, overchilling, rapid corrosion, etc)?
  - will reactor temperature run away?
  - does the three-way valve used in a pressure-relieving path have full path opening in all valve positions?

- Is on-line testing provided for safety cut-ins, cut-outs, or supplementary alarms? For any such safety system:
  - should failure or manual deactivation of the sensing-signal-control system be shown by an alarm?
  - is blowback or purge advisable on the sensing system or CV?
  - should manual bypassing of the CV be prevented by car-seal?

TOWERS AND PROCESS-RELATED DRUMS

1. Limiting Fuel to a Fire or Emergency

   - Are emergency isolation valves provided in:
     - Lines to suction and from discharge of 150kw + compressor?
     - Drum lines to/from 150 kw+ compressor interstages (>5m^3)?
     - Lines to pumps where vessel maximum working inventory plus tray holdup is:
       over 5m^3 light ends, or
       over 5m^3 HC liquid above 315^{o}C, or
       over 10m^3 HC liquid.

   - Are emergency isolation valve and driver type and installation in accordance with appropriate practices?

   - Should vapour blowdown or liquid pulldown option be applied?

2. Overpressure

   - Is PRV protection provided for the controlling contingency including utility failure, external fire, and operating failure?

- Is thermal relief required on a small liquid-filled vessel which needs no fire or other PRV?

- Can failure-open of an automatic controller overpressure a downstream vessel?

- Is path to PRV free of obstructions?
  - avoid CWMS in path
  - potential restriction by catalyst, coke, refractory, reaction products?

- Does remote but possible contingency, e.g. CSO closure, not exceed 150% DP?

- Is water separation and drawoff required to prevent delivering water to another vessel where it could vaporise at excessive rate?

3. Collapse

- Does the vessel require design for vacuum?
  - Is the atmospheric pressure boiling point of the processed material above ambient temperature? (vacuum on cooldown)

4. Reducing Leakage Risk

- Are there double valves on regularly used light ends drains/sample points?

- Are drains and vents suitably valved and blinded/plugged?

- Is winterising required because water can accumulate/freeze?

5. Furnace Fuel Gas Drum

- Does it have proper instrumentation and provision for clearing liquid? (See Furnace Checklist)
- Is the drum-to-burner line heat-traced?

(FIXED BED) SINGLE PHASE REACTORS AND STIRRED REACTORS

1. Overpressure

- Is PRV (Pressure Relief Valve) protection provided for the controlling contingency, including utility failure, external fire, and operating failure?

- PRV inlet subject to plugging?

- Are design delta P's taken into account in setting remote PRV versus reactor DP?

- Path to remote PRV subject to fouling increasing delta P over design?

- Bed subject to plugging or blockage?
  - Scale accumulation (external source)
  - Coking or other solid reaction by-product?
  - Catalyst attrition?
  - Support failure (due above design delta P) and bed shift to restrict outlet?

- Is air properly isolated from reactor when not used in regeneration? (overpressure/overtemperature)

- Would leakage of coolant from internal coil into reactor overpressure it?

2. Over temperature (Often with accompanying Overpressure)

   - Excessive preheat?

   - Exothermic reaction?
     - Quench failure or loss of external cooling?
     - Excess or deficiency of one reactant>
     - Can loss of agitation in cooled stirred reactor lead to excessive temperature/pressure?
     - Could loss of agitation in heated jacketed reactor lead to located overheating at liquid surface and subsequent runaway?
     - Local hot spot due to partial bed obstruction?
     - Excessive point or surface temperature lead to thermal decomposition or runaway?
     - Delayed onset of batch reaction while continuing reactant addition?
     - Would leakage into reactor of coolant from jacket or internal coil react exothermically?
     - Could backflow of a reactant through a depressuring system lead to or exacerbate a runaway?
     - Excessive preheat drives reaction further?
     - Appropriate normal control/emergency instrumentation provided?
     - Provision for on-line test of emergency cut-off/dump/isolation?

   - Regeneration (in place)
     - Maximum regeneration temperature provided for?
     - Too much burn medium, i.e. too high concentration?

   - (Sufficient TI/THA coverage in beds?)

3. Degradation

   - Vessel materials attacked at excessive rate during regeneration or abnormal reaction?

4. Fire

   - Is dumped catalyst pyrophoric? In-situ deactivation required?

5. Toxicity

   - Is atm. vent gas acutely toxic at any stage or regeneration or batch reaction?

   - Are there any acutely toxic emissions from dumped catalyst, regenerated or not?

FURNACE – FIREBOX SIDE

Protection Against Liquid Entry Via the Fuel Gas System

- Is fuel gas KO drum (uninsulated) provided for fuel gas/pilot gas/waste gas systems?

- Is manual block valve accessible at least 15m from furnace on each fuel?

- Is provision made for draining liquids from KO drum (preferably to closed system?)

- Does drain need backflow protection?

- Is KO drum equipped with level gauge and LHA?

- Is fuel line heat-traced/insulated from drum to burner?

Protection Against Firebox Explosion

- Does safety instrumentation protect against pilot flameout? Does PLCO on pilot gas cut pilot and all other fuels, or does flame scanner cut out all fuels?

- Are all cutout valves single-seated and dedicated?

- Do all cutout valves require manual reset?

- Is provision made for regular testing of the cutout systems (bypass circuit or short run lengths?)

- Are PHA and PLA provided on both fuel gas and pilot gas downstream of control valve?

- Are steam purge connections provided for startup? (Is valve 50 feet away?)

- Is provision made for damper failure? Fail-safe damper?

- PHA in firebox (forced draft furnaces only)?

Minimising Consequences of a Fire

- Are toe walls provided (liquid feed or fuel)?

- Are steam purge connections provided? Is smothering steam provided to header boxes (if plug headers used)? (Is valve 15m away?)

FURNACE – PROCESS SIDE

Protection Against Tube Failure

Loss of Process Flow

- Is FLA and FLCO provided to stop flow of fuel (not pilots)?

- Is individual pass flow control provided (not all-vapour)?

- Are individual pass FLA's provided (not all-vapour)?

- Are explosion hatches provided on firebox for > 70 Bar?

- Is check valve provided in coil outlet? – 14 Bar (clean service)

- Is RBV provided for coil outlet (e.g. Powerformer or P> 70 Bar)?

- Is safety valve provided in coil outlet of RBV? – steam purged if coking service?

- Is provision made for manual cutoff of feed to furnace at least 15m away?

PRESSURE RELIEF VALVES (PRVs)

1. **Application Concerns**

    - Is the PRV protection adequate for the controlling contingency, including utility failure, external fire, and operating failure?

- Is at least one PRV set at/below DP of protected equipment?

- Should two PRVs with staggered settings be considered to avoid chattering (where alternate probable contingency releases under 25 percent of maximum capacity)?

- Is PRV materials selection consistent with corrosiveness, auto-refrigeration, etc?

- Is heat tracing required to avoid inlet plugging by congealing/ freezing?

- Is blowback required or should an upstream rupture disc (RD) be used to keep coke or solids from accumulating in PRV inlet?

- Is balanced bellows PRV avoided in congealing or viscous services?

- Is balanced bellows vent routing flagged for dangerous materials?

- Should a rupture disc (RD) be considered because of 70 Bar set pressure or impact-type pressure buildup?

2. **<u>PRV with Upstream RD</u>**

- Is space between RD and PRV continuously vented to atmosphere?
  - If vent contains excess-flow check valve, is a monitor PI provided?

- Is downrating of PRV capacity consistent with code?
  - Uncertified RD downrates PRV to 80 percent capacity?

3. **<u>Piping</u>**

- Do inlet and outlet lines have same or larger flow area than PRC inlets and outlets?

- Are inlet and outlet line ratings consistent with the PRV nozzle ratings?

- Is any maintenance isolation valve on PRC inlet or outlet CSO’d?

- Are CSO’d block valves avoided in circuits protect by PRV? If unlikely closure of such CSO, would pressure not exceed 150 percent DP?

- Is PRV inlet line delta P no more than 3 percent set pressure? Especially review under 350 kPag set pressure or complex piping.

- Is maximum built-up back-pressure at PRV under 10 percent set pressure? (Balanced bellows under 50 percent set pressure?) (Note capacity correction required).

- Is maximum superimposed back-pressure at PRV under 25 percent set pressure? (Balanced bellows under 75 percent set pressure?) (Note capacity correction required.)

4. **Atmospheric Releases**

- Is possible liquid release prevented by 15 minute holdup above LHA?

- Is outlet line velocity under 75 percent sonic?

- Is 25mm snuffing steam connection to riser required?
  - 315^{o} C + HC or hydrogen or methane service.

- Is toroidal ring outlet specified for hydrogen or methane service?

- Would ignition of release give over 19 kw/m^2 to ground? – increase height or tie into closed system.

- Would ignition of release of hydrogen, methane, ethane, ethylene or HC above 315^{o}C give over 10 kw/m^2 to ground?
  - add automatic instrumentation to reduce release rate or probability.

PIPING

1. **Pressure – Temperature Rating**

- Is pipe class rating suitable for continuous conditions?

- If pipe class normal rating can be expected occasionally, does this meet the ANSI piping code limitations on
  - intermediate time: 120 percent normal press. Rating, 50 hours at one time, 500 hours/year?
  - Short time: 133 percent normal press. Rating, 10 hours at one time, 100 hours/year? E.g. result of CV failure, pump shutoff, valve closure.

- Does any line warrantee specification as a Special Line because there are short or intermediate time conditions/limitations that affect piping detail design or operating procedures?

- If piping is protected by a PRV, does the PRV setting allow for static head and flow delta P to the PRV?

- Are all valves, including both double valves and piping between them, designed for the more severe of the connecting line classifications?

- Is piping normal rating on pump discharge downstream of the pump block valve(s) suitable for the greater of:
  - Normal pump suction pressure + 120 percent of normal pump delta P? (132 percent on turbine-driven pump) or maximum pump suction pressure + normal pump delta P?

- Are suction valves and downstream suction piping on parallel pumps suitable for 75 percent of discharge DP at DT?

- Where there is an alternate source of pressure at least equal to pump discharge pressure in the discharge line of a single pump, does the pump suction valve and downstream piping rating equal discharge line rating.

- Would the pressure not exceed 150 percent DP at DT in the unlikely event of closure of a CSO valve?

2. **<u>Safety and Closed Drain System</u>**

- Are blowdown lines untrapped and sloped at least 1:480 continuously downward toward the blowdown drum?

- Are PSV release connections into blowdown lines specified to avoid risk of acoustic failure?

- On closed drain headers for flammable liquids
  - Are check valves provided at each drained vessel that could be over-pressure by other drainage into a blocked closet drain?
  - Does the header rating satisfy the highest pressure rating of equipment tied into it? (Alternate is PRV on header.)
  - Is the header material suitable for the maximum and minimum temperature resulting from discharging into it (including auto-refrigeration)?
  - Would raise to ambient temperature of a blocked closed drain system require uprating or a PRV? Also consider effect of heat tracing, if applicable.
  - Is heat tracing required because the system may receive heavy solidifiable material or water (or moisture) which may freeze?

3. **Safety-Oriented Provisions**

- Are 250mm and larger emergency isolation valves (see Tower and Drum Checklist) motor operated?

- With back leakage through a check valve would the pressure stay within 150 percent of DP?

- Where a restriction orifice (special case) or a CV is used as a means of limiting the capacity of a pressurisation path, are all the conditions satisfied?

- Are utility connections made properly?
  - Are potentially hazardous connections made by breakaway, swing elbow, etc, where consistent with operating frequency? If not feasible, is suitable blinding and blind-isolating provision made?
  - Are check valves in the downstream hard pipe for breakaway connections into process?

- Are double valves required because DT is over 1000F piping rating class is over 315^{o}C? Or slurry service 200c or above?

- Is a bleed valve (plugged) shown between double block valves in piping?

- Are light end sample outlets double valved?

- Are all tower and drum vents and drains specified?
  - Are their ratings consistent with the vessel DP?DT?
  - Are all drains valved and, where required, plugged, capped, or blinded?
  - Are double valves provided on regularly used drain connections for vessels?
  - Are drains on vessels containing auto-refrigeration liquid double-valved, with quick-opening valve nearest vessel?
  - Are vents not normally or frequently open plugged, capped or blinded, and where required, also valved?
  - Is there a 6 inch or larger vent (or vent capability) on all vessels I which manual entry is planned?

4. **Other Areas**

Is there any special consideration, either normal or connected with short-time conditions, that could promote or pre-dispose the piping to failure? For example:

- Auto-refrigeration of light ends.

- Are materials selection and piping mechanical design specified for lowest temperature during startup and shutdown as well as normal operation?
- Does any other credible operation or contingency set the controlling (minimum) DT?

- Freezing of accumulated water
  - Is heat tracing specified for piping where water freezing is possible due to accumulation or intermittent service in cold weather?

- Heat tracing selection
  - Is the tracing temperature, possibly together with the pipe materials, able to promote:
    + exothermic decomposition? (Ethylene)
    + blockage of a pressure relief path by coking or by dryout of settled slurry?
    + rapidly corrosive chemical reaction?
  - If so, is the method of tracing or the medium specified in a way to preclude? How positive?

- Stress corrosion
  - Is C.S. specified to be stress-relieved for maximum temperature vs. caustic concentration?
  - If heat tracing of caustic piping is required, is the maximum tracing temperature defined? How positive is the method of tracing temperature control?
  - Damp salt air protected against on austentic steel?

- Acid attack
  - Materials selection vs. sulfuric acid concentration/temperature control? (special concern when acid is mixed with HC or enters vessel containing HC's).
  - Material selection vs. other material acid or acidic-organic compounds?

- Metal dusting
  - For pipe running at over 480 C with high H2, CH4, or CO content, is suitable provision made (e.g. sulphide addition) to prevent catastrophic failure by metal dusting?

- Erosion
  - Has sound provision been specified for erosive services? Special concern where high velocity HC vapour steam carries or may contain abrasive solids.

- Valve closure damping
  - Should a maximum closing rate be specified for motor-operated valves or rapid-closing hand valves whose closing could cause liquid hammer?

- Is a closure damping device required on major check valves to avoid damage to rotating equipment? If so, does the damping system require specification and possible testing facilities to assure the check valve's performing its basic function under conditions unfavourable to the damping system?

SAMPLE SAFETY REVIEW CHECK LISTS

A. **Project Site Location**

1. Any exposure to or from the neighbourhood from fire, explosion, noise, air and stream pollution?
2. Adequate access for emergency vehicles?
3. Any potential blockages of access roads by railroads, highway congestion, etc?
4. Access roads well engineered to avoid sharp curves? Traffic signs provided?

B. **Building and Structures**

1. What standards are being followed in the design of stairways, platforms, ramps and fixed ladders?
2. Are sufficient general exit and escape routes available? Alternate means of escape from roofs provided? Is protection provided to persons along the line of the escape routes?
3. Adequate lighting provided?
4. Doors and windows hung to avoid projecting into or blocking walkways and exists?
5. Structural steel grounded?

C. **Operating Areas**

1. Are equipment, steam, water, air and electric outlets arranged to keep aisles and operating floor areas clear of hoses and cables?
2. Ventilation furnished for hazardous fumes, vapours, dust and excessive heat?
3. Temporary storage provided for raw materials at process points, and for finished products?

4. Where operations are hazardous from the standpoints of fire and explosion, are controls house in separate structures? If not, are control room windows kept to a minimum and glazed with laminated safety glass?

5. Are alternate escape routes to safe locations provided?

6. If needed, what type of pressure relief venting of area is furnished?

7. Do platforms provide safe clearance for safe maintenance of equipment?

8. Are nozzles and manholes sized and located for safe cleanout, maintenance operations, and emergency removal of people from vessels?

9. What protection is provided to protect against contact with hot surfaces?

10. Is head clearance adequate in walkway and working areas?

11. Is power-driven equipment adequately guarded?

12. Are manually operated valves, switches and other controls readily accessible to the operator from a safe location?

13. Are vents located so that discharges, including liquids, do not endanger personnel, public or property? Are all vents above the highest liquid level possible in the system.

14. Are free-swinging hoists avoided? Are hoists equipped with safety hooks, limit switches, if motorised?

15. Are elevators equipped with shaftway door interlocks and car gate contacts? Are there safety astragals on bi-parting doors?

16. Is every effort being made to handle materials mechanically rather than manually?

17. Are emergency showers and hose-type eye baths provided?

18. Has a safe storage and dispensing location for flammable liquid drums been provided?

19. Are there at least two exists from hazardous work?

20. Where excessively noisy operations are concerned, what measures are contemplated to reduce the noise level to a safe range?

21. Is there safe exits from manufacturing offices or laboratories?

22. Are positive electrical power disconnects being installed for purposes of lockout?

D. **Yard**

1. Are roadways laid out with consideration for the safe movement of pedestrians, vehicles and emergency equipment?

2. Are railroad car puller control stations fully protected against broken cable whiplash? How will operator be protected from being caught between cable and rope and capstan or cable drum?

3. Are flammable liquid tank car and tank truck loading and unloading docks bonded or grounded?

4. Are safe means provided on loading platforms for access to work areas of tank cars and trucks?

5. Is protection against falling furnished for employees who work on tops of railroad cars and trucks?

6. Is safe access provided to tops of storage tanks on which persons go for contents measurement and vent maintenance?

7. Is there sufficient head clearance and good visibility in walking and working areas?

8. Is yard lighting adequate?

PROCESS SAFETY REVIEW CHECKLIST

Note: Consider the check list in terms not only of steady-state operation, but also startup, shutdown, and upsets of all conceivable types.

A. **Materials**

1. What process materials are unstable or spontaneously ignitable?
   a. What elevation has been made of impact sensitivity?
   b. Has an evaluation of possible uncontrolled reaction or decomposition been made?

2. What data are available on amount and rate of heat evolution during decomposition of any material in the process?

3. What precautions are necessary for flammable materials?

4. What flammable dust hazards exist?

5. What materials are highly toxic?

6. What has been done to assure that materials of constructions are compatible with the chemical process materials that are involved?

7. What maintenance control is necessary to assure replacement of proper materials, e.g. to avoid excessive corrosion, to avoid producing hazardous compounds with reactants?

8. What changes have occurred in composition of raw materials and what resulting changes are in process?

9. What is done to assure sufficient control of raw material identification and quality?

10. What hazards can be created by failure of supply or one or more raw materials?

11. What assurance is there of adequate raw material supply?

12. What hazards can occur as a result of loss of gas for purging, blanketing, or inerting? How certain is gas supply?

13. What precautions need to be considered relative to stability of all materials in storage.

14. What fire extinguishing agents are compatible with process materials?

15. What fire emergency equipment and procedures are being provided?

B. **<u>Reactions</u>**

1. How are potentially hazardous reactions isolated?

2. What process variables could, or do, approach limiting conditions for hazard?

3. What unwanted hazardous reactions can be developed through unlikely flow or process conditions or through contamination?

4. What combustible mixtures can occur within equipment?

5. What precautions are taken for processes operating near or inside the flammable limits?

6. What are process margins of safety for all reactants and intermediates?

7. What reaction rate data are available on the normal, or abnormally possible, reactions?

8. How much heat must be removed for normal, or abnormally possible, exothermic reactions?

9. How thoroughly is chemistry of the process known? (See NFPA "Manual of Hazardous Chemical Reactions").

10. What foreign materials can contaminate the process and create hazards?

11. What provision is made for rapid disposal or reactants if required by plant emergency?

12. What provisions are made for handling impending runaways and for short-stopping an existing runaway?

13. How fully is the chemistry of all desired and undesired reactions known?

14. What hazardous reactions could develop as a result of mechanical equipment (pump, agitator, etc) failure?

15. What hazardous process conditions can result from gradual or sudden blockage in equipment?

16. What raw materials or process materials can be adversely affected by extreme weather conditions?

17. What process changes have been made since the previous process safety review?

C. **Equipment**

1. In view of process changes since the last process safety review, how was adequate size of equipment assured?

2. Are any venting systems manifolded, and if so, what hazards can result?

3. What procedure is there for assuring adequate liquid level in liquid seals?

4. What is the potential for external fire which may create hazardous internal process conditions?

5. Is explosion suppression equipment needed to stop an explosion once started?

6. Where are flame arresters and detonation arresters needed?

7. In confined areas, how is open fired equipment protected from spills?

8. What safety control is maintained over storage areas?

9. In the case of equipment made of glass or other fragile material, can a more durable material be used? If not, is the fragile material adequately protected to minimise breakage? What is the hazard resulting from breakage?

10. Are sight glasses on reactors provided only where positively needed? On pressure or toxic reactors, are special sight glasses provided which have a capability to withstand high pressure?

11. What emergency valves and switches cannot be reached readily?

12. When was pertinent equipment, especially process vessels, last checked for pressure rating?

13. What hazards are introduced by failure of agitators?

14. What plugging of lines can occur and what are the hazards?

15. What provisions are needed for complete drainage of equipment for safety in maintenance?

16. How was adequacy of ventilation determined?

17. What provisions have been made for dissipation of static electricity to avoid sparking?

18. What requirements are there for concrete bulkheads or barricades to isolate highly sensitive equipment and protect adjacent areas from disruption of operations?

D. **Instrumentation Control**

1. What hazards will develop if all types of motive power used in instrumentation should fail nearly simultaneously?

2. If all instruments fail simultaneously, is the collection operation will fail-safe?

3. What provision is made for process safety when an instrument, instrumental in process safety as well as in process control, is taken out of service for maintenance? When such an instrument goes through a dead time period for standardisation or when, for some other reason, the instrument reading is not available?

4. What has been done to minimise response time lag in instruments directly or indirectly significant to process safety? Is every significant instrument or control device backed up by an independent instrument or control operating in an entirely different manner? In critical processes, are these first two methods of control backed up by a third ultimate safety shutdown?

5. Has the process safety function of instrumentation been considered integrally with the process control function throughout plant design?

6. What are the effects of extremes of atmospheric humidity and temperature on instrumentation?

7. What gauges, metres, or recorders cannot be read easily? What modifications are being made to cope with or solve this problem?

8. Is the system completely free of sight glasses or direct reading liquid level gauges or other devices which, if broken, could allow escape of the materials in the system?

9. What is being done to verify that instrument packages are properly installed? Grounded? Proper design for the environment?

10. What procedures have been established for testing and proving instrument functions?

11. What periodic testing to check performance and potential malfunction is scheduled?

E. <u>Operations</u>

1. When was the written operating procedure last reviewed and revised?

2. How are new operating personnel trained on initial operation and experienced operating personnel kept up-to-date on plant

operating procedures, especially for startup, shutdown, upsets and emergencies?

3. What plant revisions have been made since the last process safety review?

4. What special cleanup requirements are there before startup and how are these checked?

5. What emergency valves and switches cannot be reached readily? What procedures are there to cope with these situations?

6. What safety precautions are needed in loading liquids into, or withdrawing them from, tanks? Has the possibility of static electricity creation been adequately taken care of?

7. What process hazards are introduced by routine maintenance procedures?

8. What evaluation has been made of the hazards of sewered materials during normal and abnormal operation?

9. How dependable are supplies of inerting gas and how easily can supplies to individual units be interrupted?

10. What safety margins have been narrowed by revisions of design or construction in efforts to debottleneck operations, reduce cost, increase capacity, or improve quality?

11. What provisions does the operating manual have for coverage of startup, shutdown, upsets and emergencies?

12. What economic evaluation has dictated whether a batch process or a continuous is used?

F. **Malfunctions**

1. What hazards are created by the loss of each feed, and by simultaneous loss of two or more feeds?

2. What hazards result from loss of each utility, and from simultaneous loss of two or more utilities?

3. What is the severest credible incident, i.e. the worst conceivable combination of reasonable malfunctions, which can occur?

4. What is the potential for spills and what hazards would result from them?

G. **Location and Plot Plan**

1. Has equipment been adequately spaced and located to permit anticipated maintenance during operation without danger to the process?

2. In the event of the foreseeable types of spills, what dangers will there be to the community?

3. What hazards are there from materials dumped into sewers of neighbouring areas?

4. What public liability risks from spray, fumes, mists, noise, etc exist, and how have they been controlled or minimised?

ELECTRICAL SAFETY REVIEW CHECK LIST

A. **Design**

1. How completely does the electrical system parallel the process?

   a. What faults in one part of the plant will affect operation of other independent parts of the plant?

   b. How are instruments for a plant protected from faults or other voltage disturbances?

2. Are interlocks and shutdown devices made fail-safe?

   a. What is the need for each interlock and shutdown used?

   b. Are interactions and complications minimised?

   c. Is continued use of protective devices ensured?

   d. What requirements or standards were used in selecting the hardware?

3. How has the area NEC classification been established and hardware and techniques selected?

   a. What process details affect the classification, group, and division?

   b. What "UL approved" hardware is unavailable for this job? Does this require testing?

   c. Are any new techniques being applied on this job?

4. Is the electrical system simple in schematic and physical layout so that it can be operated in a straightforward manner? (This minimises human error in switching for isolation and load transfer).

5. What electrical equipment can be taken out of service for preventive maintenance without interrupting production? How?

6. How is the electrical system instrumented so that equipment operation can be monitored? Will this eliminate downtime due to equipment failures caused by unknown overloading?

7. What are the overload and short circuit protective devices?

   a. Are they located in circuits for optimum isolation of faults?

   b. What is the interrupting capacity?

   c. How are they co-ordinated?

   d. What instructions are furnished for field testing on installation and for testing during the life of equipment?

8. What bonding and grounding is provided?

   a. Does it protect against static buildup?

   b. Does it provide lighting protection?

   c. Does it provide for personnel protection form power system faults?

9. Is lighting adequate?

   a. Adequate for safe normal operation?

   b. Adequate for normal running maintenance?

   c. Adequate for escape lighting during power failure?

10. Is tankage grounding co-ordinated with catholic protection?

11. Are power disconnects, starters, etc accessible during mishaps?

12. Is communication provided to operate a complex safely (telephones, radios, signals, alarms, etc)?

13. Are spacings and clearances furnished for normal traffic maintenance, and for fire fighting?

14. Is there a schedule for checking operability of interlocks?

15. Where sequence controllers are used, is there an automatic check, together with alarms, at key steps after the controller has called for a change, and is there a check together with alarms at key steps before the next sequence changes?

BOILER AND MACHINERY CHECKLIST

A. **Boilers**

1. Safety Valves

   a. Are long and large vent lines supported?

   b. What drain connections are provided?

   c. Is first drum valve set to relieve boiler working pressure?

   d. Is the last drum valve set to pop at or below 103 percent of boiler working pressure?

2. Blow-Off Piping

   Is steel piping of next higher gauge than required used for boiler pressure, avoided sharp radius ells, and sloped all lines and drained all low points in the lines?

3. Feedwater Piping

   Is the bypass around the feedwater regulator accessible form the operating level and located where the drum level gauge glass can be seen? Are electrically-driven feedwater pumps duplicated by steamdriven pumps?

4. Steam Outlet Piping

   a. Are there separate non-return and header stop valves where two or more boilers discharge into the same piping system?

   b. Is there a visible free blow and drain in piping between non-return and header stop valves?

   c. Are there condensate drain provisions for all sections of piping?

5. Drum Water Level – Attended Operation

   a. Are there both high and low water alarms?

   b. Is there a low water cut-off of gas or oil burners? (If drop or loss of plant steam pressure does not jeopardise process safety).

   c. Is gauge glass visible from feedwater regulator bypass valve?

   d. Is remote drum level gauge independent of drum level controls?

6. Drum Water Level – Unattended Operation

   a. Are high and low boiler water levels monitored?

   b. Are two independent low water level switches interlocked with gas or oil burner safety shut-off valves?

7. Gas Burner Control and Piping – General

   a. What type of plug cocks have been provided for manual shut-off service?

   b. Is there in-line strainer in gas line ahead of all regulating and safety shut-off valves?

   c. Do you provide for stable gas pressure regulation at all loads? This may require a small regulator in parallel with the full-sized regulator for start-up or low fire service.

   d. Is there a double safety shut-off and vent valve arrangement? What type of reset is there for each valve?

   e. What type of automatic fuel-air ratio control is used?

   f. Is there separate pressure regulation of pilot gas?

   g. Is safety control circuit DC, or 120v AC with the safety controls in the ungrounded circuit?

   h. Do you ensure positive, tamper-proof time period to provide minimum of 6 air changes in combustion changer before light-off? Air flow rate during purge should be at least 70 percent of maximum capacity.

i. Are controls of interlocks installed to prevent burning firing rate from being reduced below minimum stable flame?

j. Are controls or interlocks installed to prevent burner light-off when insufficient combustion air flow is present?

k. What interlock is there to assure low-fire burner light-off?

8. Additional gas burner controls and interlocks for unattended operation.

   a. Is main burner flame monitored?

   b. Are following interlocks for safety shut-down furnished?

      1. High gas pressure?

      2. Low gas pressure?

      3. Low combustion air flame?

      4. Low boiler water (double switched)?

   c. Is there flame scanner response line of 2 – 4 seconds?

   d. Is there tamper-proof programmed light-of sequence to purge, light and prove pilot, light and prove main flame, post purge?

   e. How have you set up positioning fuel-air ratio controls?

   f. Is there a self-checking feature for flame scanner and flame scanner relay circuitry?

9. Are provisions made in the old burner controls and piping for each of the following items?

   a. Oil line strainer

   b. Oil pressure control

   c. Heater for heavy oil

   d. Single safety shut-off valve

   e. Start-up recirculating line for heavy oil

   f. Positive fuel-air ratio control

g. Low oil pressure alarm or interlock

h. Low oil temperature alarm or interlock for heavy oil

i. Low atomising steam pressure alarm or interlock

j. Positive purge cycle and low fire start controls

k. Interrupted pilot

10. Additional oil burner controls and interlocks for unattended operation:

    a. Are interrupted and proved pilot and monitoring of main oil burner flame with interlock to close safety shut-off valve during flame failure provided?

    b. Are the following interlocks in use of safety shut-down of burners?

        1. Low oil temperature – for heavy oils?

        2. Low oil pressure?

        3. Low combustion air flow?

        4. Low atomising steam pressure?

        5. Low boiler water (double switched)?

    c. Is a tamper-proof programmed light-off sequence provided?

    d. Are positioning fuel-air ratio controls used?

11. Are the following interlocks in use for pulverised fuel furnaces for shut-down of furnace?

    a. Igniter flame failure?

    b. Coal “flame-out” for changeover period from coal to oil?

    c. Loss of forced or induced draft or low combustion airflow?

    d. Excess furnace pressure?

    e. Is there an igniter shut-off interlock on loss of igniter fuel pressure?

B. **Piping and Valves**

1. Were piping systems analysed for stresses and movement due to thermal expansion?

2. Are piping systems adequately supported and guided?

3. Are piping systems provided for anti-freezing protection, particularly cold water lines, instrument connections and lines in dead-end service such as piping at standby pumps?

4. Are provisions made for flushing out all piping during start-up?

5. Are cast iron valves avoided in strain piping?

6. Are non-rising stem valves being avoided?

7. Are double block and bleed valves used on emergency interconnections where possible cross-contamination is undesirable?

8. Are controllers and control valves readily accessible for maintenance?

9. Are bypass valves readily reached for operation? Are they so arranged that opening or valves will not result in an unsafe condition?

10. Are any mechanical spray steam desuperheaters used?

11. Are all control valves reviewed for safe action in event of power or instrument air failure?

12. Are means provided for testing and maintaining primary elements of alarm and interlock instrumentation without shutting down processes?

13. What provisions for draining and trapping steam piping are provided?

C. **Pressure and Vacuum Relief**

1. What provisions are there for flame arresters on discharge of relief valves or rupture discs on pressurised vessels?

2. What provisions are there for removal, inspection, and replacement of relief valves and rupture discs, and what scheduling procedure?

3. What need is there for emergency relief devices: breather vents, relief valves, rupture discs, and liquid seals? What are the bases for sizing these?

4. Where rupture discs are used to prevent explosion damage, how are they sized relative to vessel capacity and design?

5. Where rupture discs have delivery lines to or from the discs, how are they sized relative to vessel capacity and design?

6. Where rupture discs have delivery lines to or form the discs, what has been done to assure adequate line size relative to desired relieving dynamics? To prevent whipping of discharge end of line?

7. What equipment, operating under pressure, or capable of having internal pressures developed by process malfunction, is not protected by relief devices and why not?

8. Is discharge piping of relief valves independently supported? Make piping as short as possible and with minimum changes in direction.

9. Are drain connections provided in discharge piping of relief valves where condensate could collect?

10. Are relief valves provided on discharge side of positive displacement pumps; between positive displacement compressor and block valves; between back-pressure turbine exhaust flanges and block valves?

11. Where rupture discs are in series with relief valves to prevent corrosion on valve or leakage of toxic materials, install rupture disc next to the vessel and monitor section of pipe between disc and relief valve with pressure gauge and pressure bleed-off line. Have any rupture discs been installed on discharge side of relief valve?

12. What provisions for keeping piping to relief valves and vacuum breakers at proper temperature to prevent accumulation of solids from interfering with action of safety device are provided?

D. **<u>Machinery</u>**

1. Are adequate piping supports and flexibility provided to keep forces on machinery due to thermal expansion of piping within acceptable limits?

2. What is separation of critical and operating speeds?

3. Are check valves adequate and fast acting to prevent reverse flow and reverse rotation of pumps, compressors and drivers?

4. Are adequate service factors on speed changing gears in shock service provided?

5. Are there full-flow filters in lube-oil systems serving aluminium bearings?

6. Are there provisions for draining and trapping steam turbine inlet and exhaust lines?

7. Are there separate visible-flow drain lines from all steam turbine drain points?

8. Are driven machines capable of withstanding tripping speed of turbine drain points?

9. Are non-lubricated construction or non-flammable synthetic lubricants used for air compressors with discharge pressures of greater than 75 psig to guard against explosion?

10. What provisions are made for emergency lubrication of critical machinery during operation and during emergency shutdowns?

11. Are provisions made for spare machines or critical spare parts for critical machines?

12. Are there provisions for operation or safe shutdown during power failures?

13. Are vibration switches on alarm or on interlock for cooling tower fans provided?

FIRE PROTECTION CHECKLIST

1. If the building has enclosed walls and the construction of occupancy has combustibles, what kind of automatic sprinklers (wet or dry pipe systems) are provided?

2. If the building has open walls and the construction or occupancy has combustibles, how much water spray protection (HAD's or pilot head heat actuating systems) has been provided?

3. What existing hydrants serve the area or project? What additional ones are to be provided?

4. What fixed or potable monitor nozzles (on hydrants or separate) are provided for coverage of manufacturing facilities or storage facilities in open areas (not within open or closed wall buildings)?

5. Have the underground fire mains been extended or looped to supply additional sprinkler systems, hydrants and monitor nozzles? Dead ends should be avoided. What sectional control valves have been provided?

6. Are small hose standpipes provided inside of buildings?

7. What type, size, location and number of fire extinguishers are needed?

8. What flammable liquid storage tank protection has been provided? Foam? Dikes with drain valves outside the dike?

9. Where have total flooding or local-application carbon dioxide systems been provided?

10. Is load-bearing structural steel, which could be exposed to flammable liquid or gas fire, fireproofed to a sufficient height above ground level to protect the steel? (This height varies from 10 to 12m depending on additional fire protection features).

11. How has adequate drainage been provided to carry spilled flammable liquids and water used for fire-fighting away from buildings, storage tanks, and process equipment?

12. What protection has been provided for dust hazards?

13. What is the capacity of fire water supplies? What is the maximum fire water demand?

14. How long will supplies meet this maximum demand?

15. What is the spacing of flammable liquid storage tanks?

16. What is the estimated probably maximum loss (PML)?

17. What is the approximate “hold-up” of flammable liquids in the manufacturing equipment broken down by flash points?

18. What attention has been given to protection of process equipment from external fire?

19. Are liquid inventory tanks near or under the ground instead of elevated?

20. Is the area pad or flooring designed to conduct spill liquid away from process equipment? What facilities are provided for drainage?

21. How have major storage tanks or vessels been located to minimise hazard to process equipment in the event of rupture or burning?

22. Are all structures constructed of non-combustible materials and fire walls, partitions or barricades provided to separate important property damage values, high hazard operations and units important to continuity of production?

FURTHER GUIDANCE ON GUIDEWORD SELECTION

			Heat Exchanger				Column		
Deviation	**Line**	**Pump**	**Shell**	**Tube**	**Vessel**	**Tank**	**Top**	**Bottom**	**Scrubber**
Purpose	What	What	What	What	What	What	What	What	What
	Where	Where	Where	Where	Where	Where	Where	Where	Where
	When	When	When	When	When	When	When	When	When
	How	How	How	How	How	How	How	How	How
	Why	Why	Why	Why	Why	Why	Why	Why	Why
Pressure	No	No			Vacuum	Vacuum	Vacuum	Vacuum	Vacuum
	Low	Low	Low	Low	Low	Low	Low	Low	Low
	High	High	High	High	High	High	High	High	High
	Over Pressure	Over Pressure	Over Pressure	Over Pressure	Over Pressure	Over Pressure	Over Pressure	Over Pressure	Over Pressur
	Differential	Differential	Differential	Differential	Differential	Differential	Differential	Differential	Differential
Temperature	Low	Low	Low	Low	Low	Low	Low	Low	
	High	High	High	High	High	High	High	High	
	Overheat	Overheat	Overheat	Overheat	Overheat	Overheat	Overheat	Overheat	
	No Heat Source	No Heat Source	No Heat Source	No Heat Source	No Heat Source	No Heat Source	No Heat Source	No Heat Source	
Flow	No	Stops Pumping	No	No	Low Level	Low Level	Low Level	Low Level	Low Level
	Low	Blocked Disc	Low	Low	High Level	High Level	High Level	High Level	High Level
	High	Cavitation	High	High	In/out	In/out	Dumping	Dumping	Dumping
							Flooding	Flooding	Flooding
	Reverse	Reverse	Reverse	Reverse	Reverse	Reverse			
	Siphon	Drain			Siphon	Siphon			
	Leakage	Leakage	Leakage	Leakage	Leakage	Leakage	Leakage	Leakage	Leakage
	Two Phase		Two Phase	Two Phase					
	Degass		Degass	Degass	Overflow	Overflow			
			Inerts	Inerts	Inerts	Inerts			
Composition	Wrong Fluid		Wrong Fluid	Wrong Fluid	Wrong Fluid	Wrong Fluid	Wrong Fluid	Wrong Fluid	Wrong Fluid
	Low comp.						Low comp.	Low comp.	Low comp.
	High						High	High	High
	Cross Contam.		Cross Contam.	Cross Contam.	Cross Contam.	Cross Contam.	Cross Contam.	Cross Contam.	Cross Contan
	Cleaning		Cleaning	Cleaning	Cleaning	Cleaning	Cleaning	Cleaning	Cleaning
	Solids		Solids	Solids	Solids	Solids	Solids	Solids	Solids
Mechanical		Loss Power	Leak to Tube	Leak to Shell					
		Loss seal purge	Fouling	Fouling					
		Seal Leak							
		Seal Fail							
	Loss of control	Loss of control	Loss of control	Loss of control	Loss of control	Loss of control	Loss of control	Loss of control	Loss of contr
	Corrosion	Corrosion	Corrosion	Corrosion	Corrosion	Corrosion	Corrosion	Corrosion	Corrosion
	Utility failure	Utility failure	Utility failure	Utility failure	Utility failure	Utility failure	Utility failure	Utility failure	Utility failure

PROPOSED HAZOP GUIDE WORDS FOR MECHANICAL/HUMAN INTERFACE SYSTEMS

CONVENTIONAL HAZOP	Modified HAZOP Guide Words	Suggested Basis for Developing Questions for a Drilling Rig
NO FLOW	Proposed action fails No movement No response to intended movement	Equipment in failed condition at status check or fails when activated Pipework or hose failure Incorrect operation (operator error) Lifting equipment fails to lift or fails during lifting
REVERSE FLOW	Opposite or alternative action Reverse movement	Equipment activates but responds incorrectly Hose connections incorrect
MORE FLOW	More action or movement than intended or required	Other actions carried out at same time out of sequence Lifting equipment not controlled correctly Failure of hydraulic control systems Excessive velocity of rotary table or lifting equipment Combined drilling and production operations Incorrect movement of drilling rig, ball joint and telescopic joint movements Dragged anchors etc.
REDUCED FLOW	Reduced actions or movement	Slow operator response (fatigue) Slow operation due to faulty equipment Failed or restricted pipework Inadequacy or failure of hydraulic control systems Pipework or equipment leakage Procedures not followed correctly or cut short
INCREASED PRESSURE	Increased loading	Excess torque generated by hydraulic equipment Over-loading of cables or lifting equipment Excessive hydraulic pressures Pipework surge problems and damage caused by liquid slugs Incorrect pressure differentials (hydraulics/downhole pressure control) Weather, wind, rough seas etc Design specifications exceeded
REDUCED PRESSURE	Reduced Loading	Restricted pump suction line Leakage from pipework (undetected) Passing relief or isolation valves Demand by hydraulic equipment exceeds capacity of system Incorrect pressure differential (hydraulics/downhole pressure control)