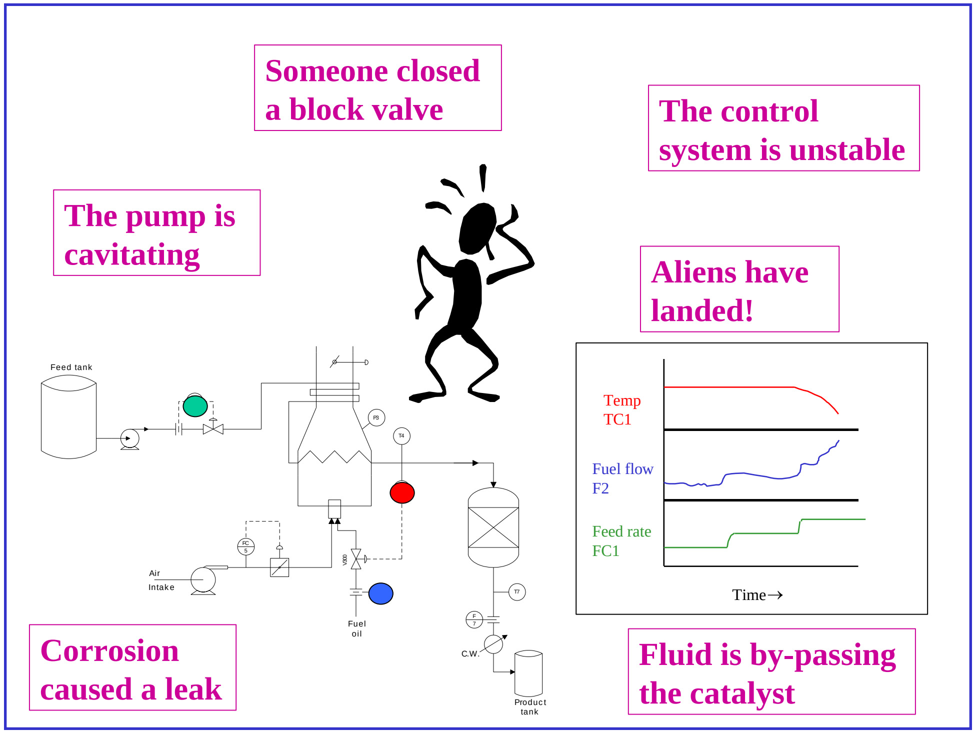
# Process Trouble Shooting




## The Final Topic for Chemical Engineering 4N04!

**Presented by**

## Thomas Marlin

http://teresaslaugh.blogspot.ca/2010_05_01_archive.html

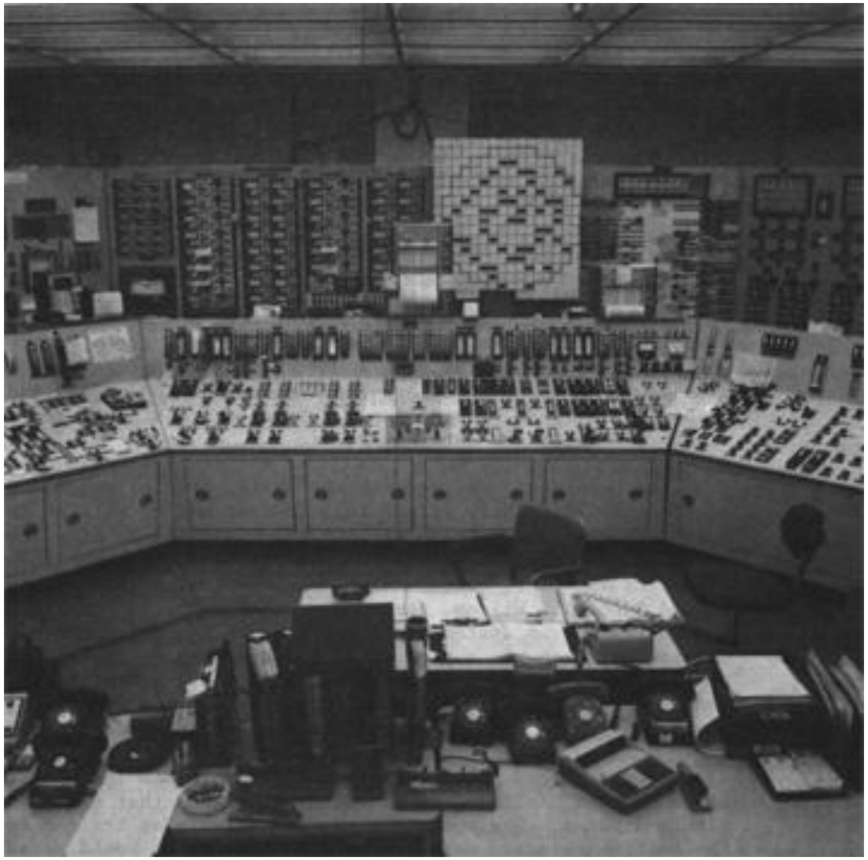
# A typical day of plant operation

You have worked ½ of your shift and things are pretty quiet.  An alarm sounds to inform you that the main cooling pumps have shutdown and the control rods have been lowered in the reactor to reduce heating.  While not desirable, you are not worried, because the backup pumps have started to provide cooling to the reactor.  This happens occasionally.

You observe that the safety valve opened and then closed after a short time, which is reasonable to relieve steam pressure due to the  short-term overheating.

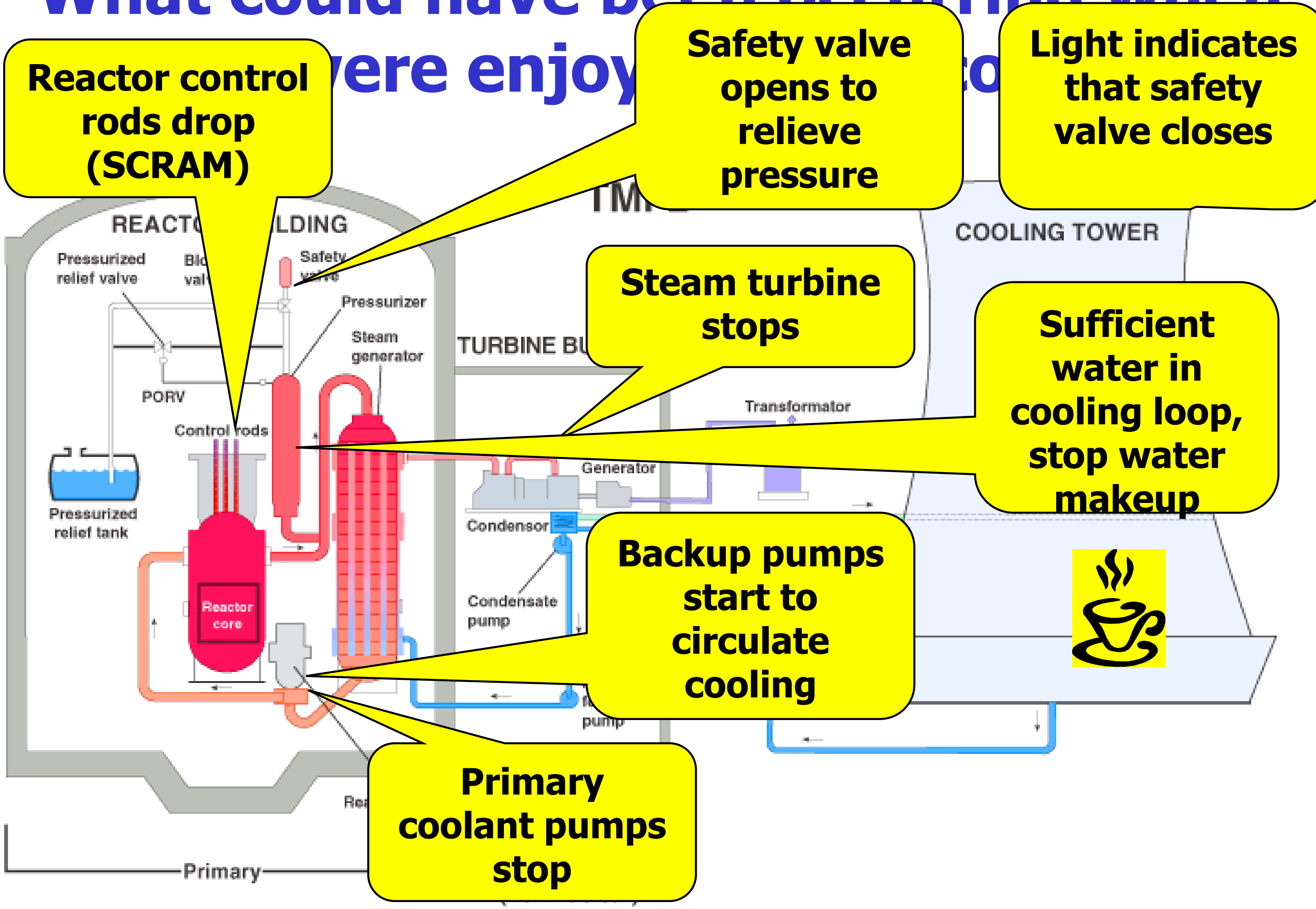
The cooling water level surrounding the reactor is appropriately high, so you turnoff the emergency makeup water pumps.

Things are getting back to normal, so time to enjoy that cup of coffee and get back to the discussion of the Penn State basketball team.



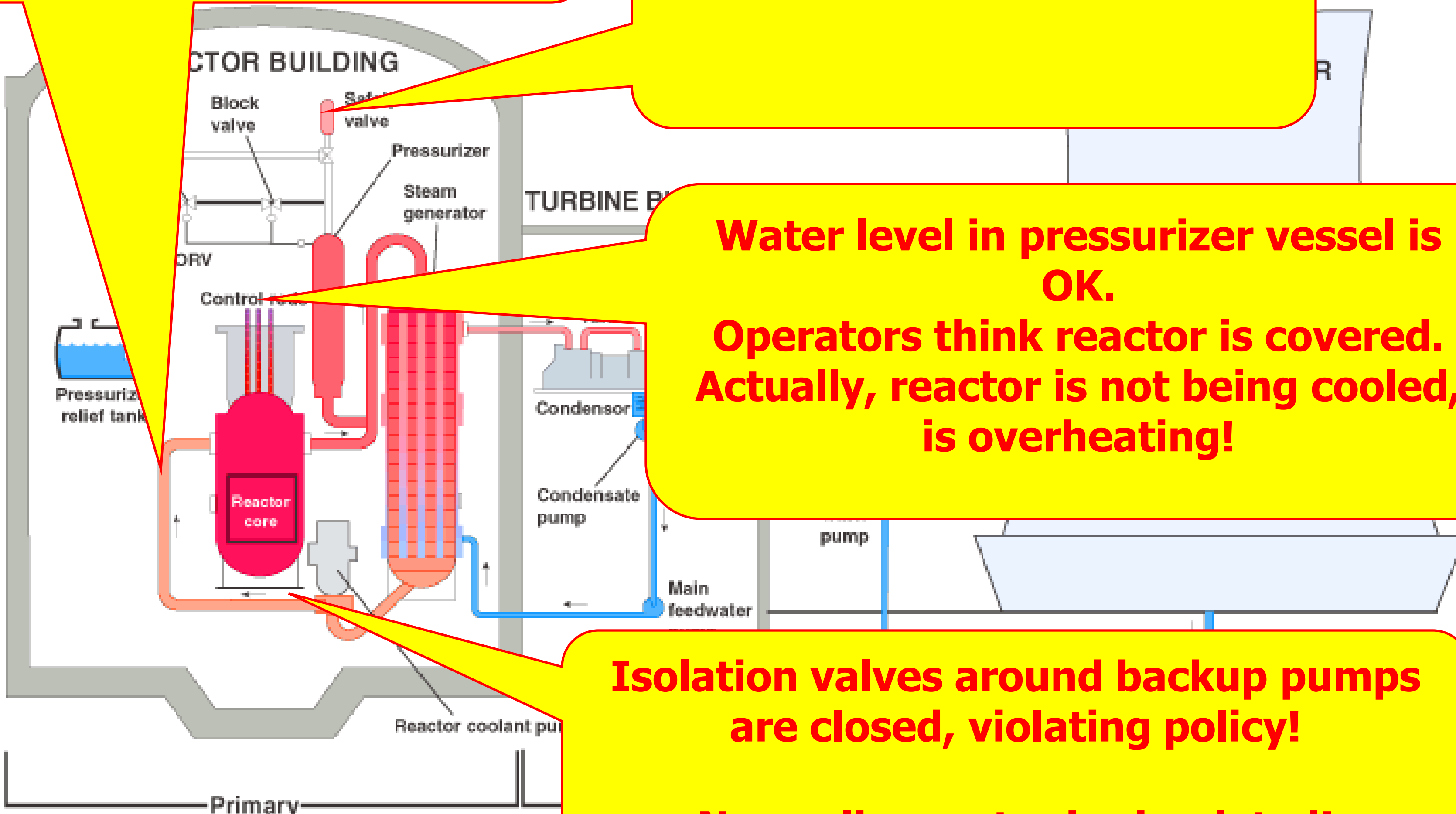
http://www.animatedsoftware.com/hotwords/control_room/control_room.htm

# What could have been occurring when
# …vere enjoy… co…




http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

# curring when you were
# ng your coffee?




Since operators think water is OK, they shutoff emergency water makeup pumps!

Safety valves remained open! Water continues to escape!

Water level in pressurizer vessel is OK.
Operators think reactor is covered.
Actually, reactor is not being cooled, is overheating!

Isolation valves around backup pumps are closed, violating policy!

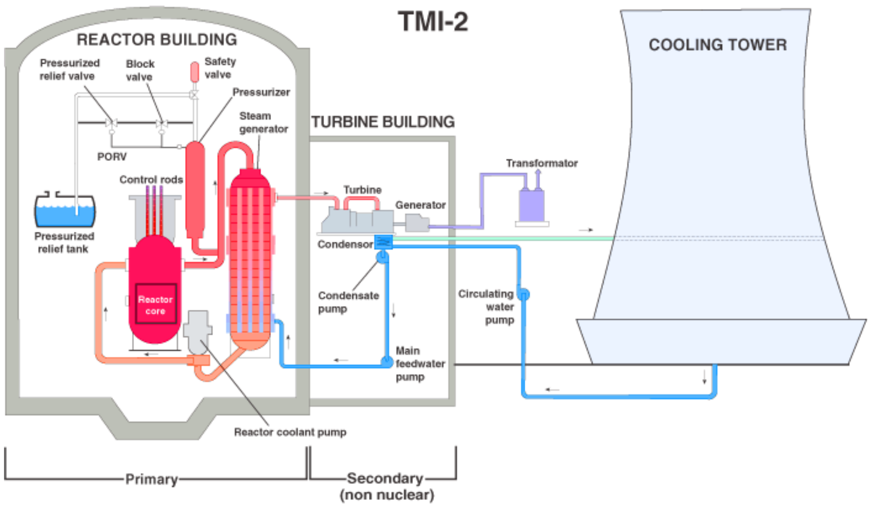
No cooling water is circulated!

# We would like to become famous for our engineering achievements, but …. not this way!!


**Three Mile Island Nuclear Power Plant**

# What is needed to prevent such incidents?

- **Design** process plants that can be monitored and diagnosed easily with "handles" for quick response

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http://www.animatedsoftware.com/hotwords/control_room/control_room.htm

- **Operate** using **Excellent Trouble Shooting Skills** for **personnel and standard operating procedures for key faults (likely and high impact)**

**Emphasis of this class**

# Three Mile Island Worksheet

| Design deficiencies | Operations deficiencies |
|---|---|
| | |

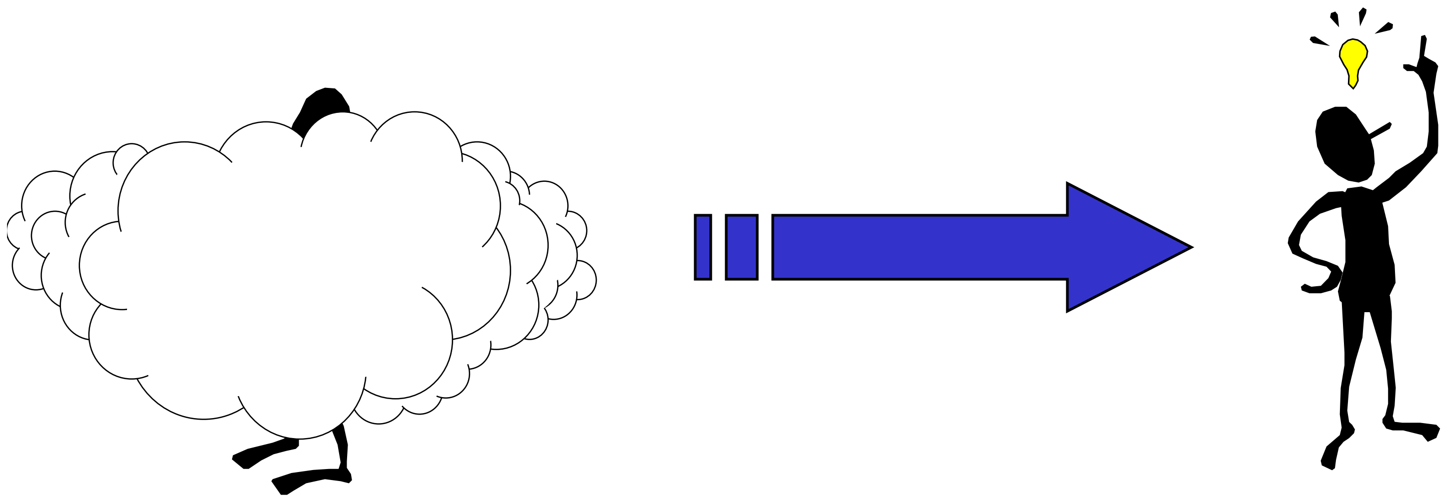
# Three Mile Island Worksheet

## Solution

| Design deficiencies | Operations deficiencies |
|---|---|
| 1. No indication that block valves are closed<br>2. No indication that cooling water flow is too low<br>3. Indicator of safety valve position relied on power, not position<br>4. No clear measure that steam was being released (e.g., temperature after relief valve)<br>5. No indication of true water level in reactor shell | 1. Improperly closed block valves<br>2. Incorrect understanding of cooling water cycle (that pumps could be blocked)<br>3. Incorrect understanding of relief indicator (due to improper training)<br>4. Incorrect understanding of level sensor in pressurizer<br>5. Tunnel vision – measurements did not confirm that the process was on a safe path |

# TROUBLE SHOOTING IN THE PROCESS INDUSTRIES

**A “bread and butter” skill for all chemical engineers!**



No systematic method. No way to focus technical knowledge.

Uses systematic TS method and builds technical knowledge through experience.

# Process Trouble Shooting – A Short Perspective

## Goals/Motivation for Students

- **Google "troubleshooting, engineering" yields over 31,000,000 hits with many being job postings**
- **If you <u>design plants</u> - You must design so that others can monitor and diagnose**
- **If you <u>manage plant operations</u> – You will be troubleshooting**
- **If you are a <u>consultant</u> – No one calls you until something has gone wrong; you will be trouble shooting**
- **If you are interested in profit – Trouble Shooting is a <u>profitable service</u> to provide to customers**

# Process Trouble Shooting – A Short Perspective

## Where does it fit in the Chem. Eng. Skills/Knowledge?

Most courses give teach fundamentals in a "single direction" that emphasizes design. e.g.,

"Given exact information about the flow, temperature, feed concentration, …. , determine the volume for the reactor"

Trouble shooting requires that the same fundamentals be applied with different sets of knowns and unknowns, e.g.,

"Given an uncertain set of conditions in the reactor, are the measured values possible/likely?"

"If the flow of coolant stopped (were reduced, …), what would be the effect on the measured variables?"

"What are conditions in the reactor that would cause the observed rapid (gradual) decrease in conversion?"

# Process Trouble Shooting – A Short Perspective

## Where does it fit in the Chem. Eng. Skills/Knowledge?

**Most courses give teach fundamentals in a "single direction" that emphasizes design. e.g.,**

**"Given exact information about the fl**
**concentration, …. , dete**

**TROUBLE SHOOTING PROVIDES NEW, INTERESTING CHALLENGES THAT REINFORCE AND EXTEND PRIOR LEARNING OF FUNDAMENTALS**

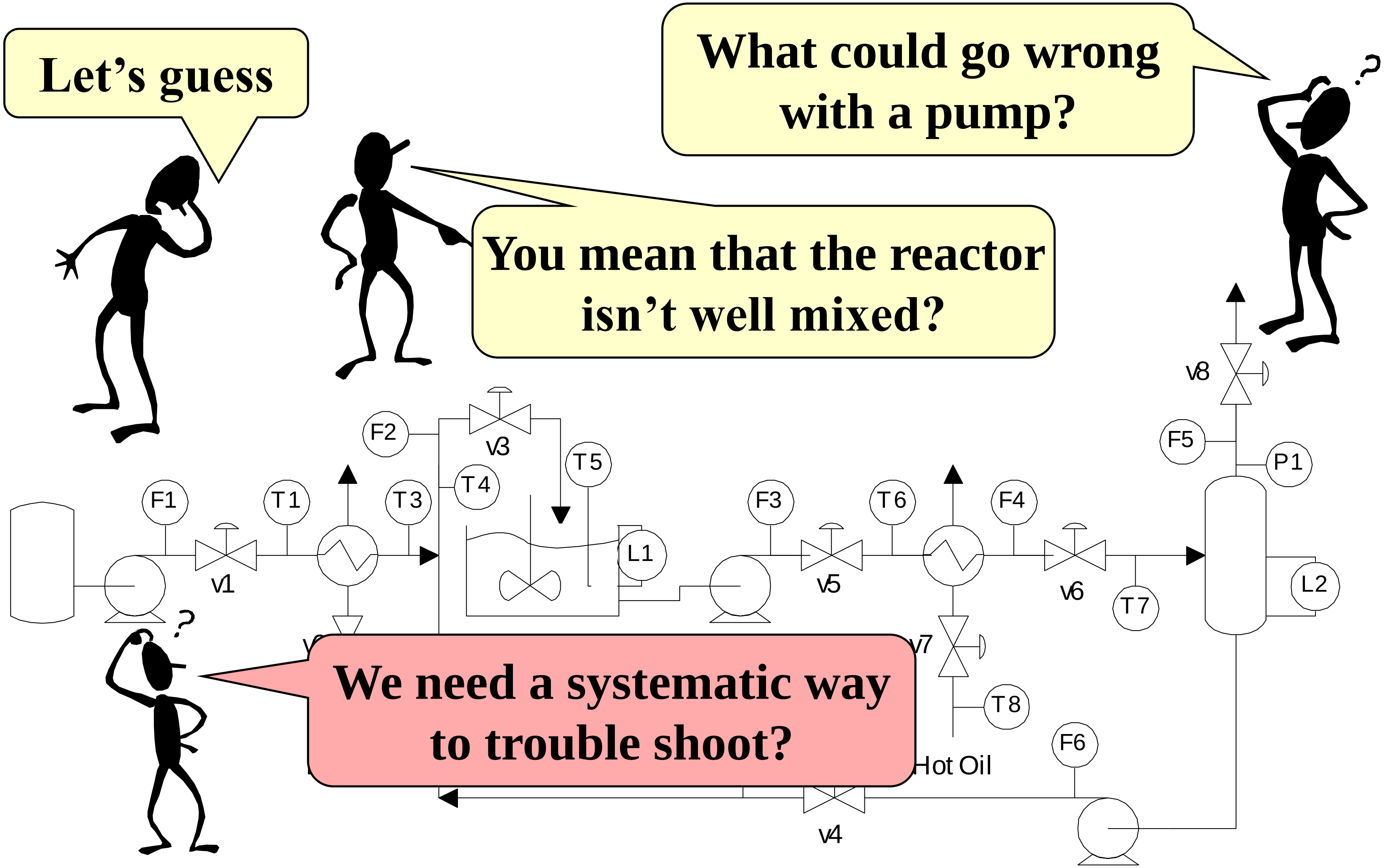
**T**
**als be**
**and unknowns, e.g.,**

**certain set of conditions in the reactor, are the measured values possible/likely?"**

**"If the flow of coolant stopped (were reduced, …), what would be the effect on the measured variables?"**

**"What are conditions in the process that would cause the observed rapid (gradual) decrease in conversion?"**

# The yield of valuable product has decreased by 10% over the last week. Fix the problem!



# PROCESS TROUBLESHOOTING - A WORTHWHILE EDUCATIONAL TOPIC

## Can we teach Trouble Shooting?

- People improve with experience and education
- Students benefit from a systematic method and early experience
- TS motivates and guides learning of process principles and designs that can be easily monitored
- TS gives new insights for life-long skill improvement

# Process Trouble Shooting Presentation and Evaluation

- **Classes with numerous Mini-Workshops**
- **Additional Exercises performed as class-team**
- **Group (Triad) Workshops during two-hour tutorials**
- **Potential question on final examination**

# PROCESS TROUBLESHOOTING

**What do we want to learn?**

**Attitude : We want to distinguish normal variation from a severe fault and find the root cause of a fault.**

**Skill: We can apply a systematic Trouble Shooting Method**

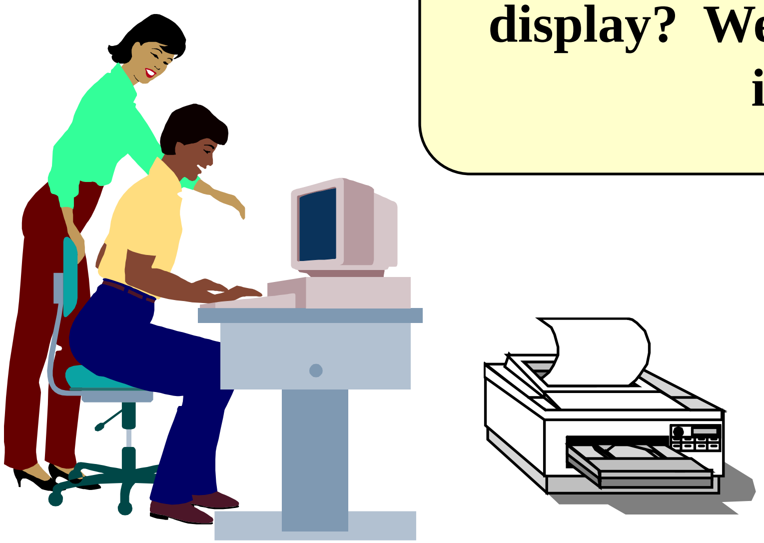
**Knowledge: We understand process principles and equipment**

# What is Trouble Shooting?

- Application of **Problem Solving** methods to the diagnosis and improvement after deviations occur in a system.

**We do this in our every-day lives all the time**

**Why doesn't the printout look like the screen display? We only have 30 minutes to hand in our 4L02 report!**



# PROCESS TROUBLESHOOTING

1. Engage

2. Define

3. Explore

4. Plan

5. Implement

6. Evaluate

## SKILLS

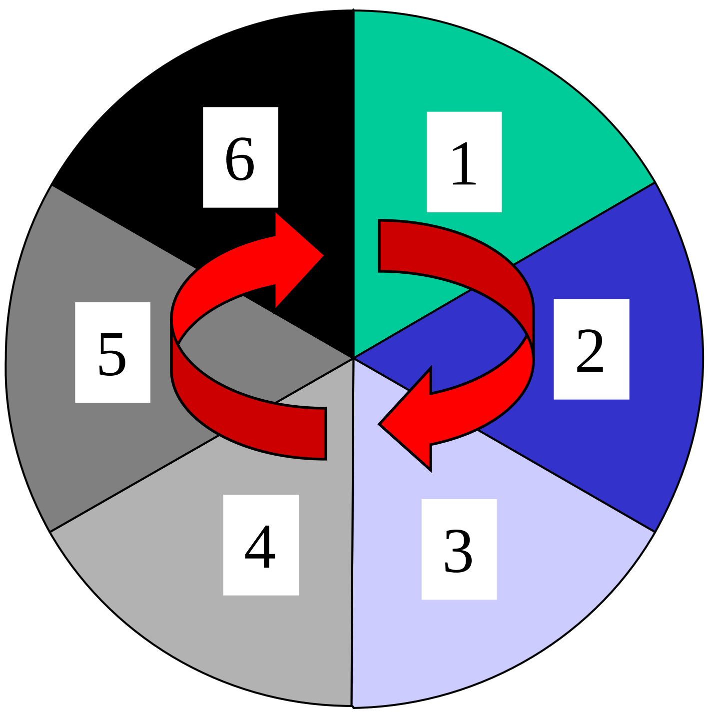
## Tailor well known Problem Solving Method

1. **Build on prior PS experiences**
2. **Give you a procedure to adapt to many situations**
3. **Consistent with methods used in engineering practice**

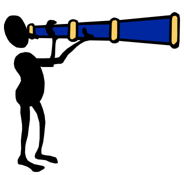
# TROUBLE SHOOTING APPLIES THE

# SIX-STEP PROBLEM SOLVING METHOD

It’s a circle, not a linear method



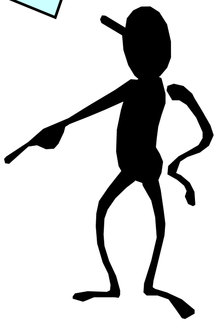

- Step 1 - Engage
- Step 2 - Define
- Step 3 - Explore
- Step 4 - Diagnosis
- Step 5 - Implement
- Step 6 - Lookback



We look back after each step.  Are the results of previous steps (future state, process understanding,….) still appropriate?

# Trouble Shooting Worksheet

PS method tailored to Trouble Shooting.



**1. Engage**

**2. Define**

Current, desired,deviation

Desired final state: SMARTS

The problem IS/IS NOT

**3. Explore**

a. Fundamentals

b. Relevant Changes

c. Experience factors

d. Data consistency

e. Bounds on behavior

**4. Plan Solution, Perform Actions, Find Root Cause**

| WORKING HYPOTHESES | INITIAL EVIDENCE (Support, Disprove, Neutral) | | | | | DIAGNOSTIC ACTIONS (Support, Disprove, Neutral) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | A | B | C | D |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

Explain each diagnostic action here

Don't memorize. We will have a worksheet.

| Action | Complete these after brainstorming | | | Outcome of action |
|---|---|---|---|---|
| | Sequence # | Time | cost | |
| A | | | | |
| B | | | | |
| C | | | | |

**5. Do it : based on root cause**

a. Operation or equipment

b. Short / Long term solutions

c. Continue to trouble shoot

d. Clear communication, plan, and documentation

**6. Evaluate: Check & Create a Lookback**

a. Predictions vs. results

b. Extra benefits

c. Potential problems

d. Prevent reoccurrence

e. Experience factors

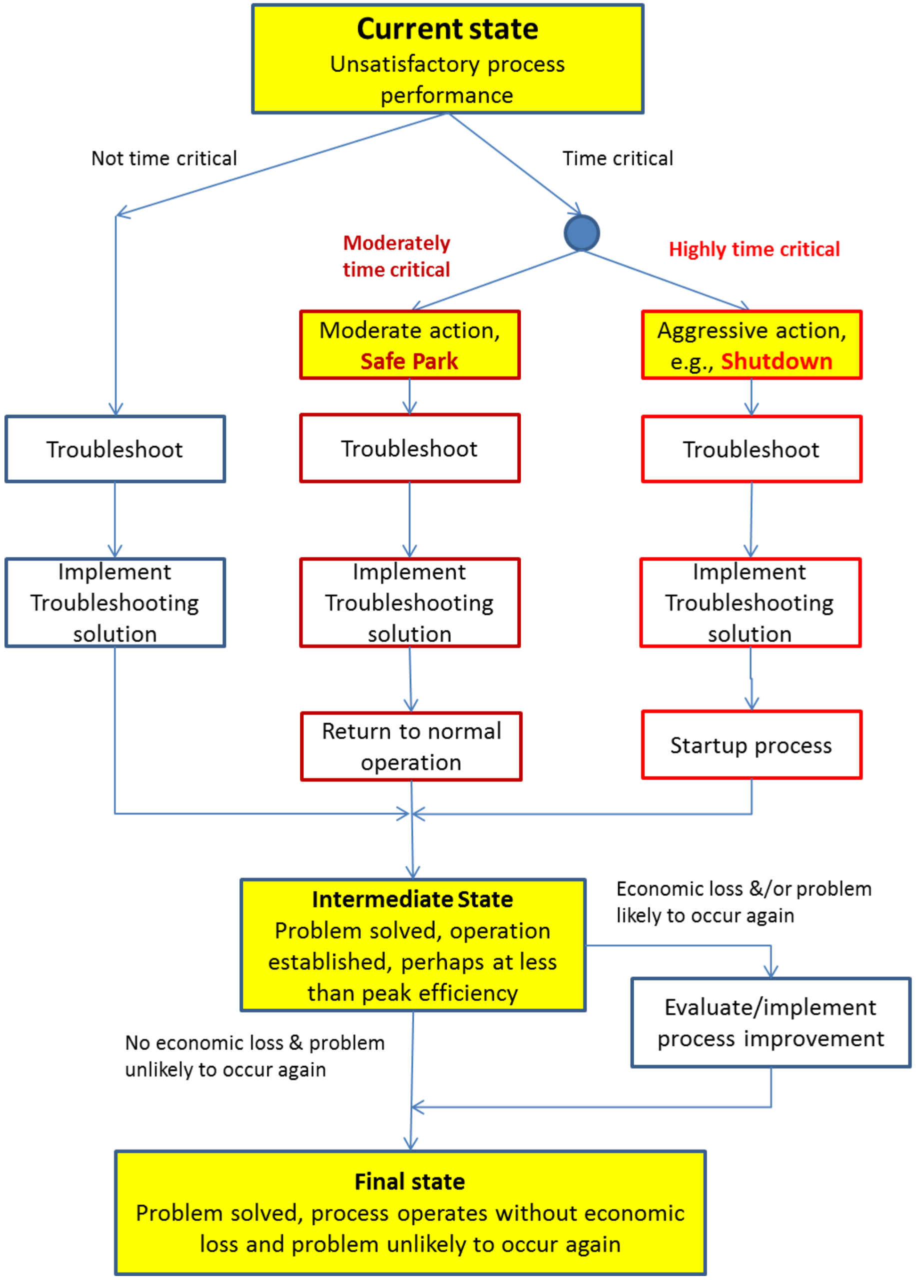
f. Improved plant monitoring

# Process troubleshooting
## (Considering time)

**Maintain the process in a safe condition – ALWAYS!**

- **Not Time-critical**
- **Safe Park**
- **Shutdown**

**Reviewed initially and throughout the TS procedure**



# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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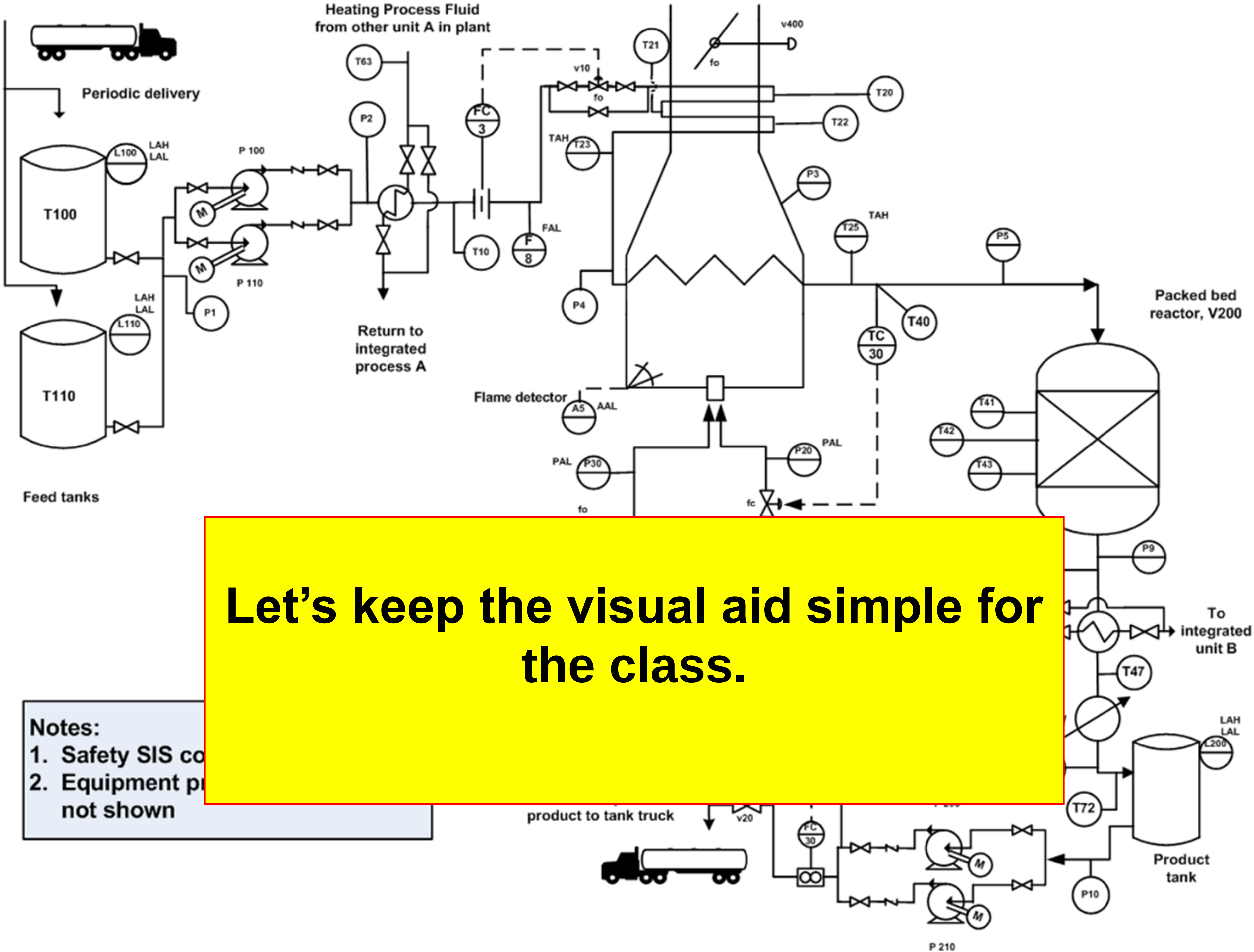
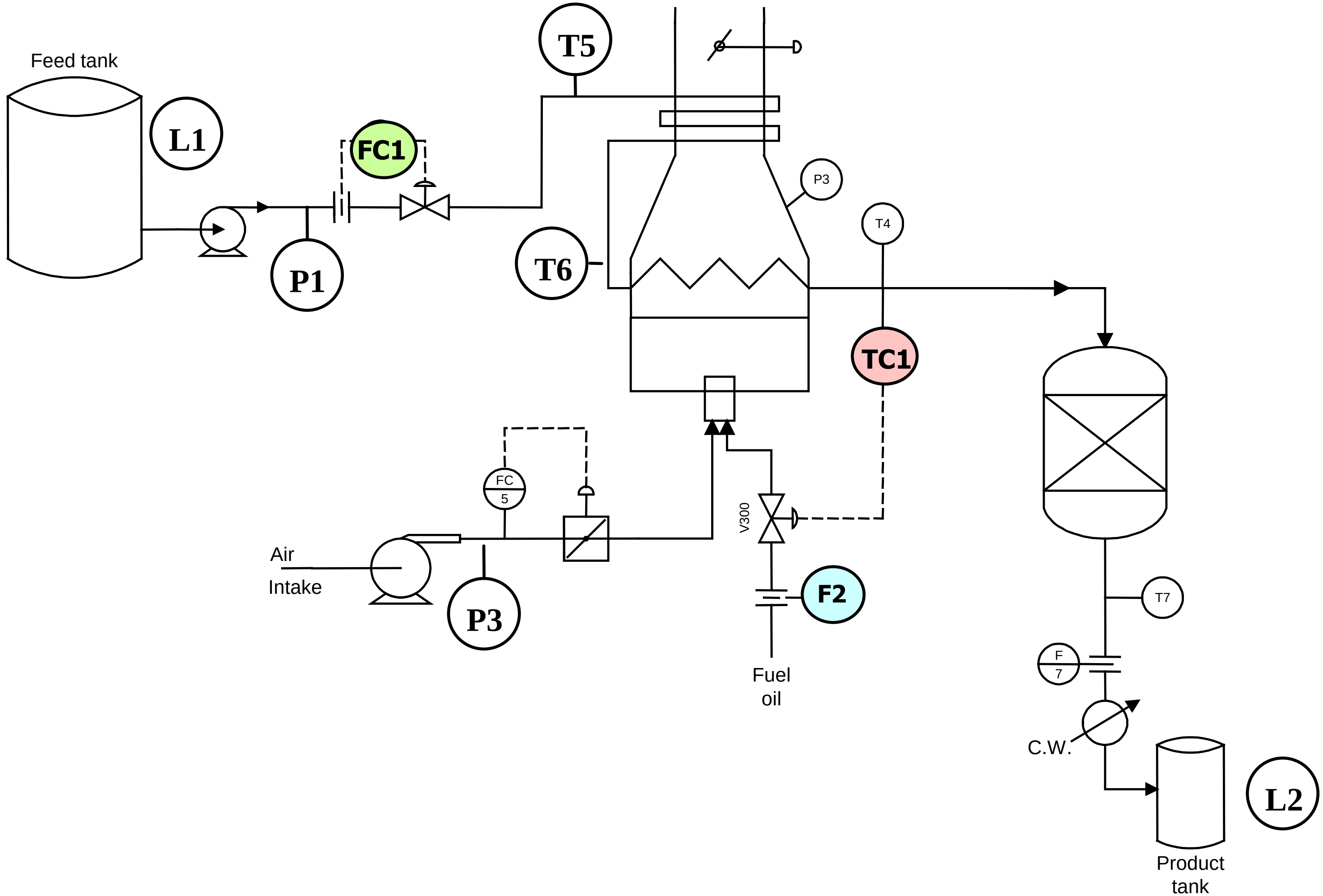
## Trouble-shooting class organization

- We will introduce the complete method along with good and poor actions while solving one process example – the fired heater drooping temperature.
- Then, we will solve a couple more examples during a workshop. These will be on the two-tower distillation process.
- We will review some of the trickier aspects in some additional topics on troubleshooting.




**Let's keep the visual aid simple for the class.**

## CLASS EXAMPLE: Let’s discuss this process with preheat, packed bed reaction, and effluent cooling



## CLASS EXAMPLE: Fired Heater Scenario

You are working at your first job, in which you are responsible for the chemical plant in Figure 1. Good news, the market for your product has been increasing. During the morning meeting, you have asked the operator to slowly increase the feed flow rate. In addition, the maintenance group will be calibrating all flow meters this week.

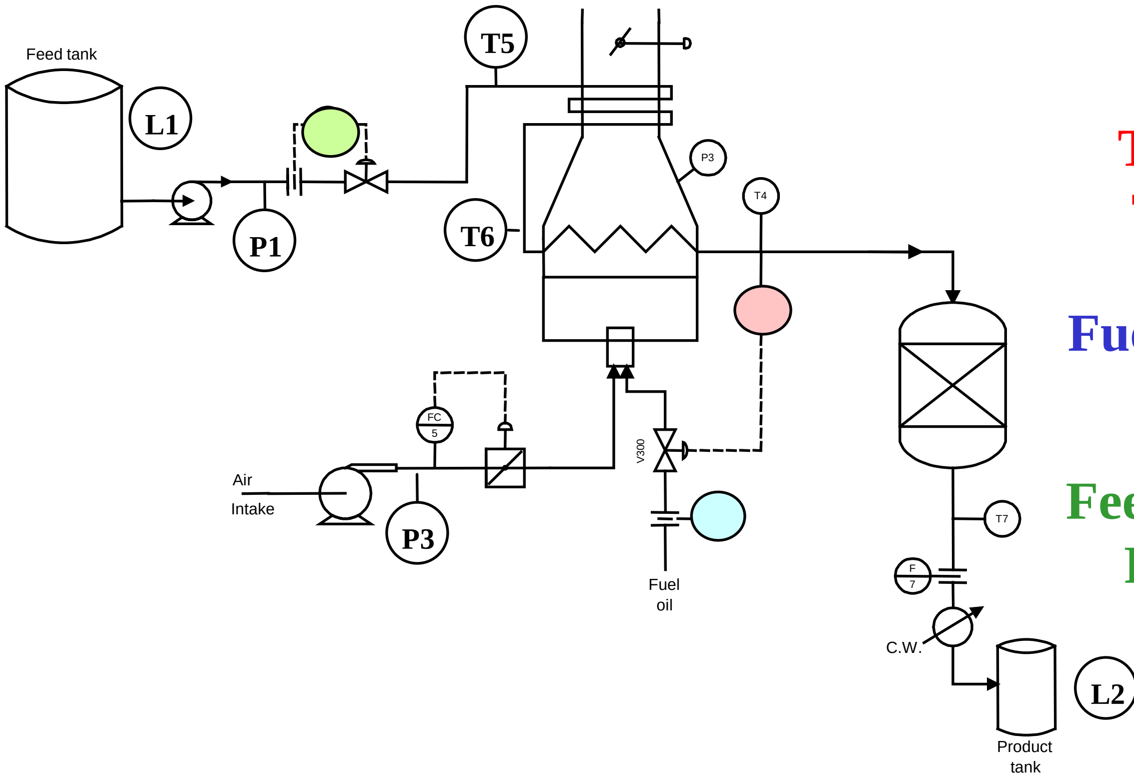
In the afternoon, you are visiting the control room to check on the instrumentation maintenance. The technicians have completed two sensors and are on a break. The operator notes that the plant changed feed tanks recently. One of the outside operators has reported an unusual smell around the feed pump.

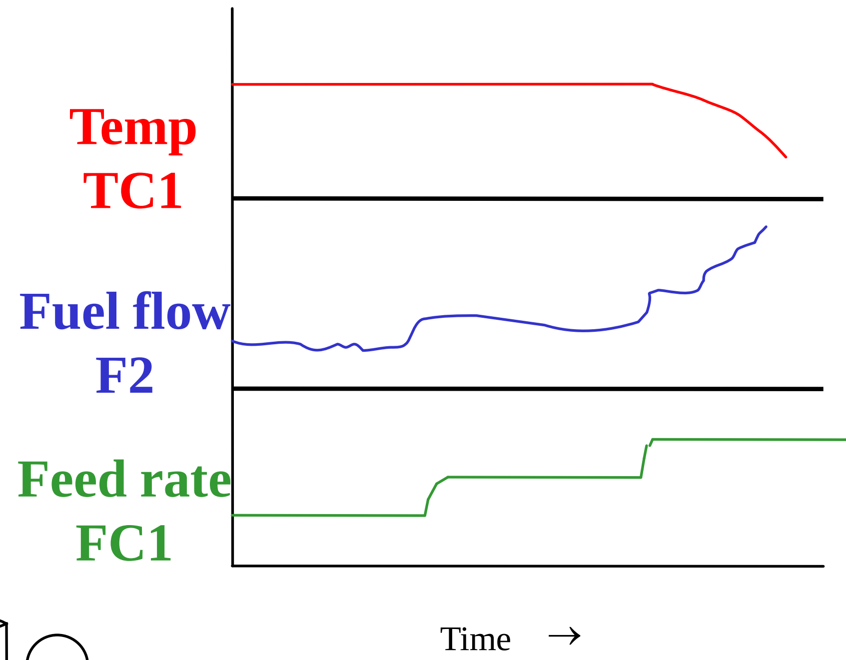
The control room operator asks for your assistance. She shows you the trend of data in the figure. This doesn't look usual to you, and she believes that it is caused by improper behavior of the stack damper.

Fortunately, you learned trouble-shooting skills in university. Now, you can combine your skills with the operator's insights to solve the problem.

**CLASS EXAMPLE: Trouble Shooting**

**The operator does not like these trends**



# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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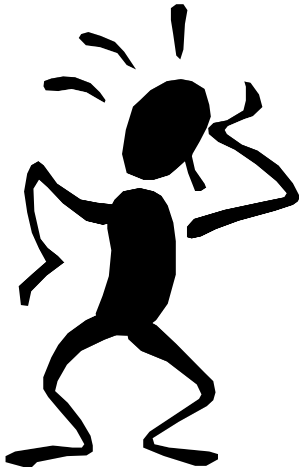
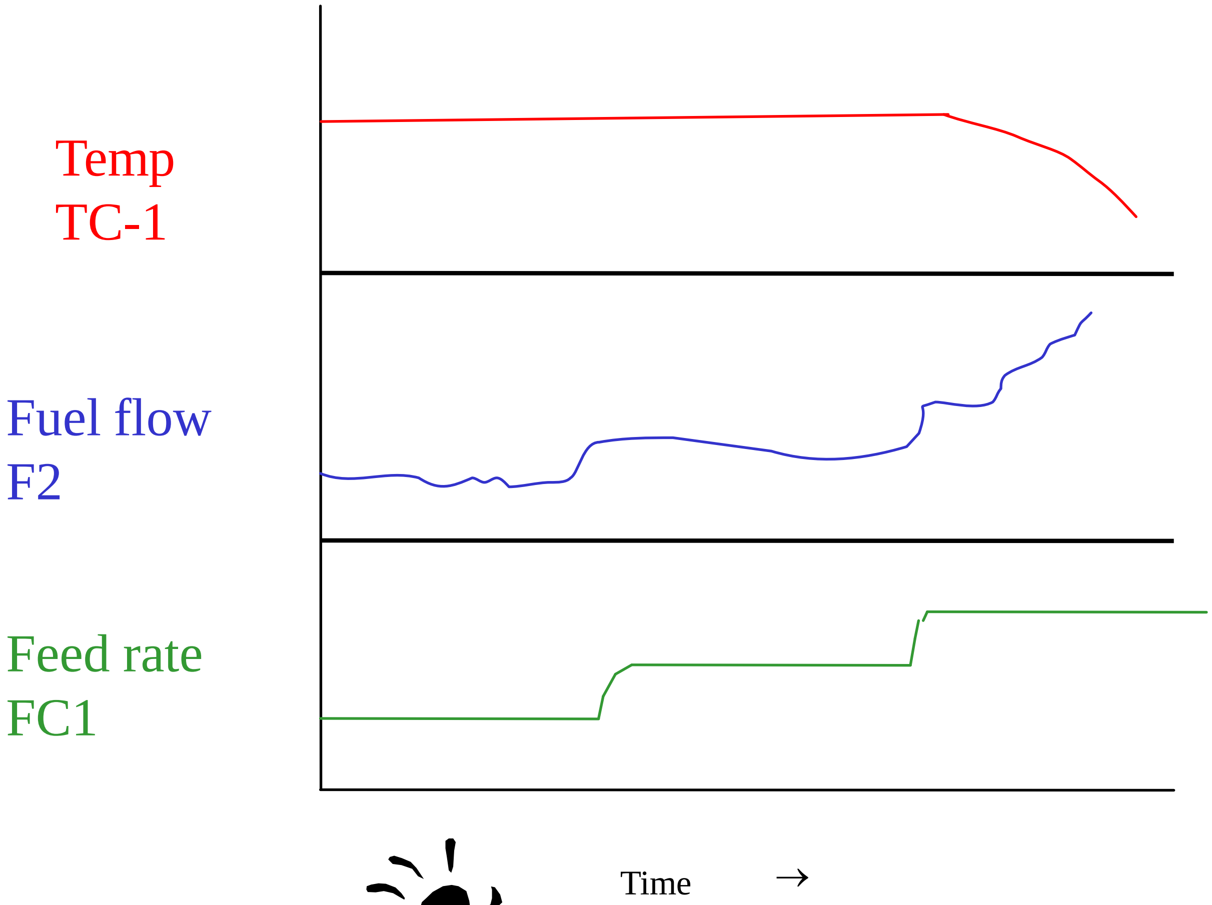
## Deal with emotions

**Manage stress**



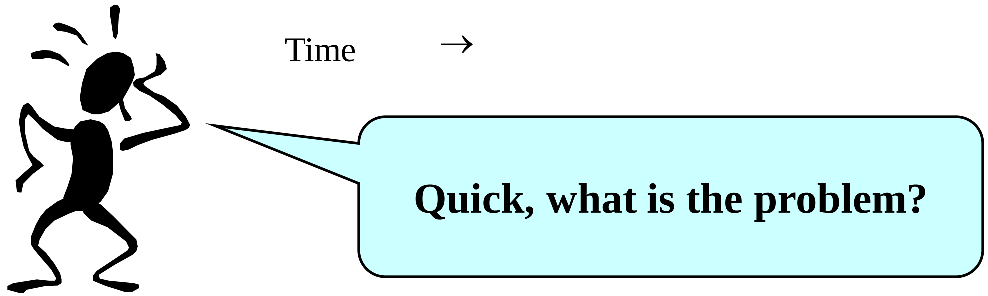
**First few times we won't achieve perfection**

# PROCESS TROUBLESHOOTING




## CLASS EXAMPLE

**This is the plot of selected data that is concerning the operator.**

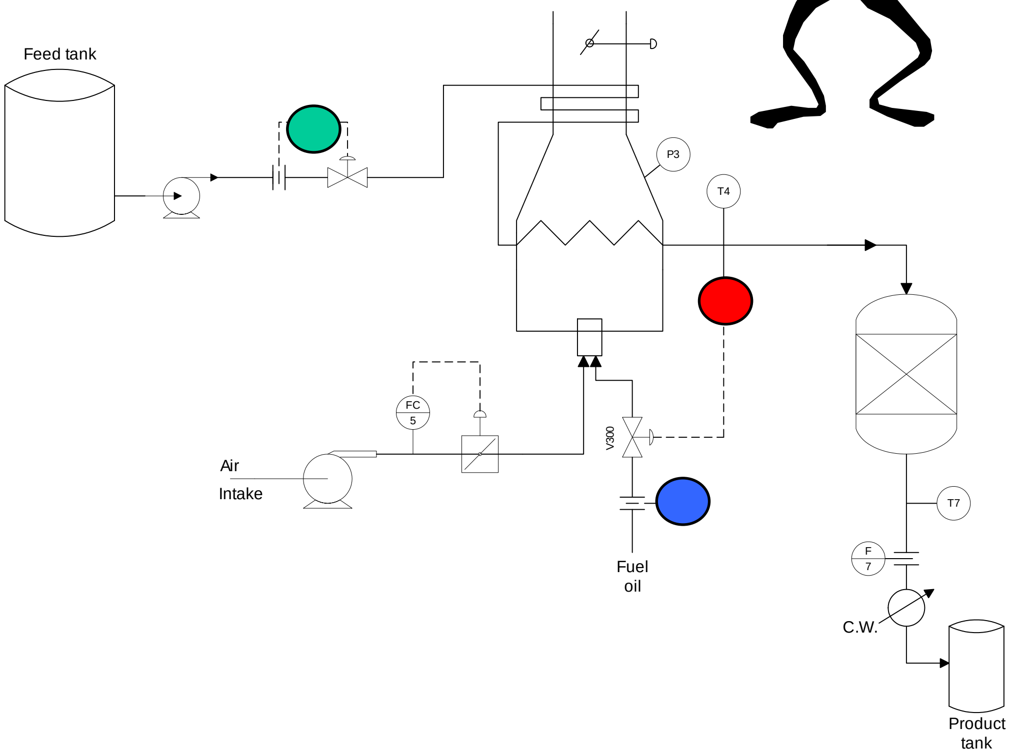


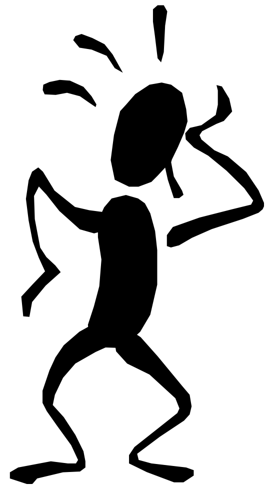
The reactor is leaking

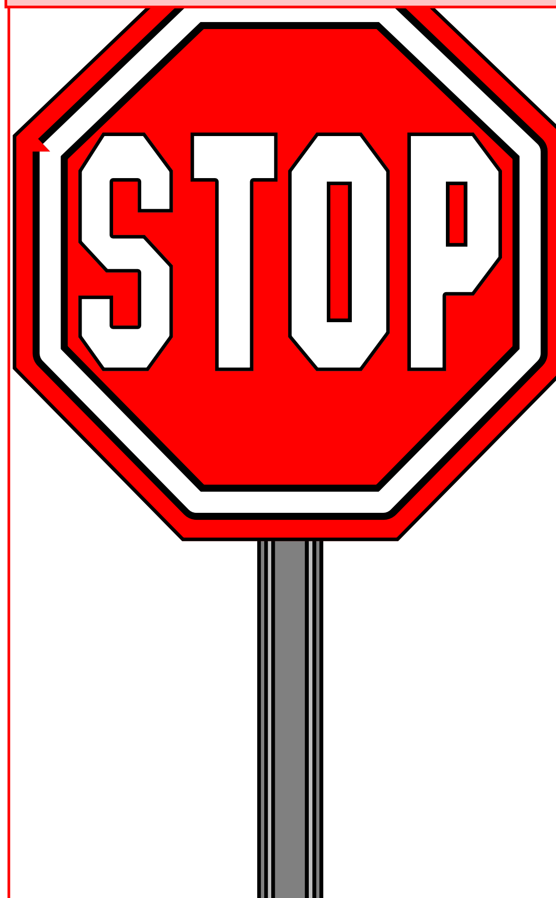
# ENGAGE

able

The pump is cavitating






**Don't guess!**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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6. Evaluate

Some initial attitudes that are **not helpful**.

- What, why haven't you done something?
- I don't understand, but I better do something fast.
- Oh dear, run!!
- {I hope no one knows that I don't know the answer.  I have no confidence}

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
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Some initial attitudes that are helpful.

- Listen and read carefully. Do not expect the answer to be obvious.
- Work with others in solving the problem.
- Use the standard TS method!
- Apply process principles.

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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## TS IS GOAL-DIRECTED

**Draw a sketch and note key variables.**

**What should be / is actually happening?**

**Therefore, the deviation is: xxxxxxxx**

| Current state | Initial state | Final state |
|---|---|---|
| Unprofitable and perhaps, unsafe | Safe and achieved quickly | Efficient, may take time |

**Safety, major equipment damage and large $ loss take precedence.**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

**Current state**
Unprofitable and perhaps, unsafe

**Initial state**
Safe and achieved quickly

**Final state**
Efficient, may take time

## DEFINE STATE(S): SMARTS-$

- **S**pecific and **M**easurable
- **A**ttainable
- **R**eliable
- **T**imely (can be achieved in the appropriate time)
- **S**afely
- **$ = C**ost-**E**ffective

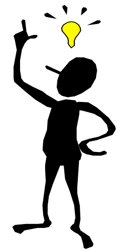
# CLASS EXAMPLE

**Should be:**

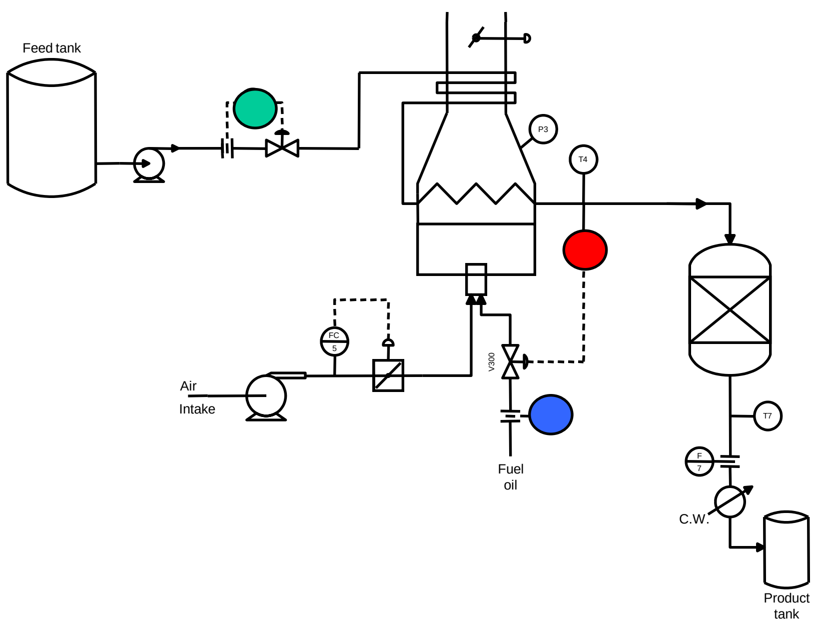
**Actually:**

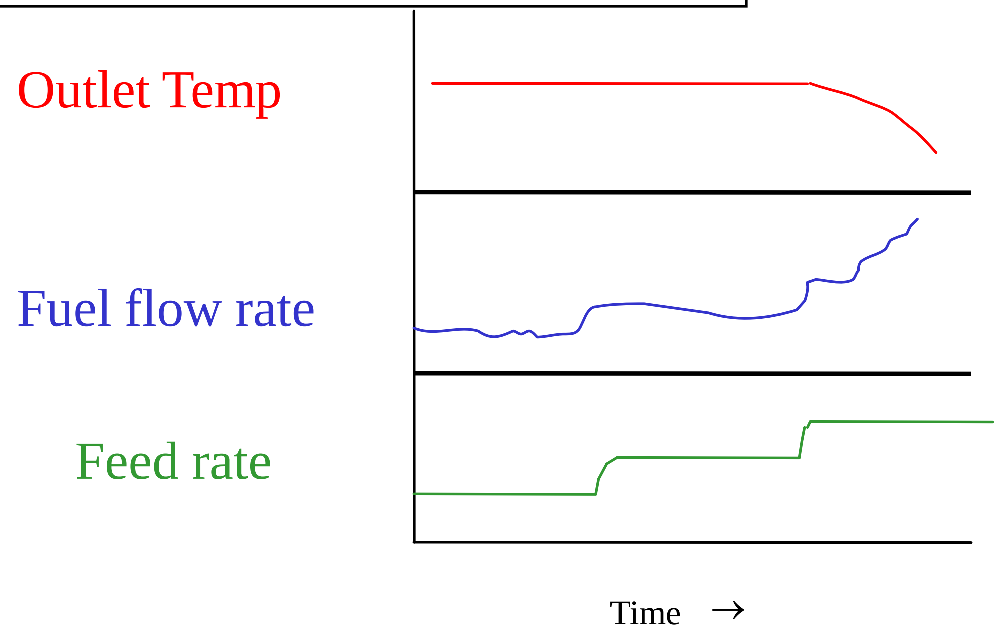
**Initial state:**

**Final State:**



**Let’s complete the definition.**



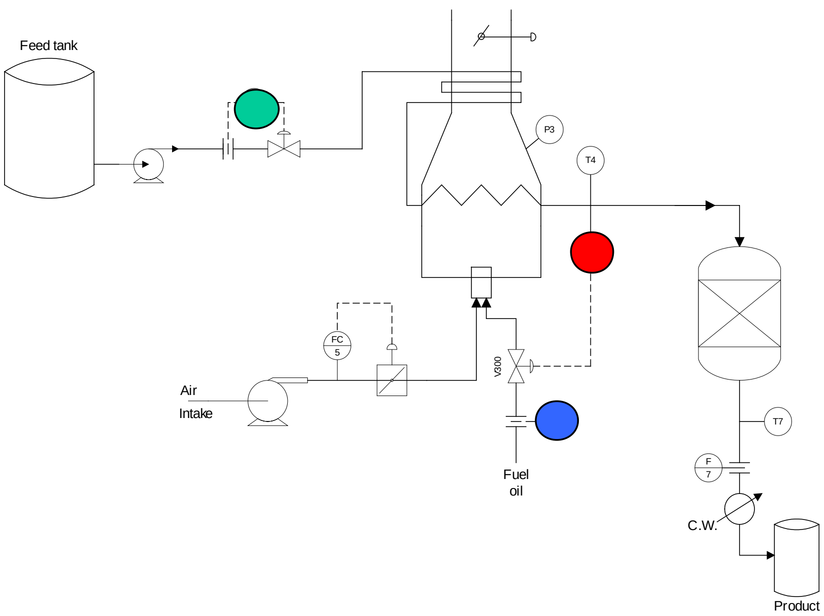
**Should be**: controlling temperature

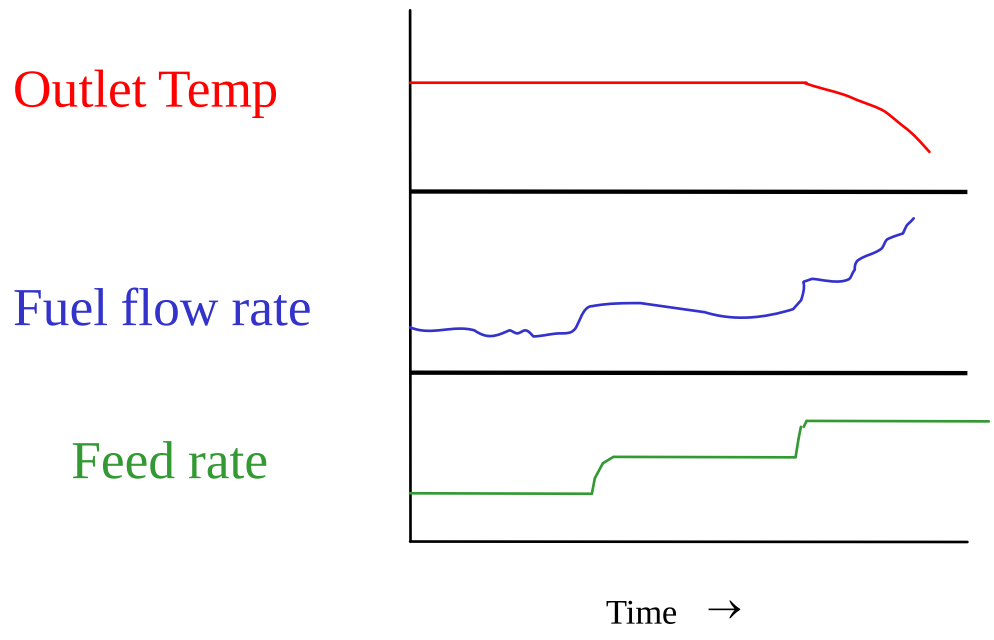
**Actually**: temperature is falling fast, but fuel is increasing?

**DEFINE**

**Initial state**: achieve **safe** operation fast!

**Final State**: Produce desired amount of product



# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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## Rich understanding

- Fundamentals
- Check information and data!!!
- Relevant changes
- Startup
- Trends
- Quick bounds

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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- **Fundamentals**

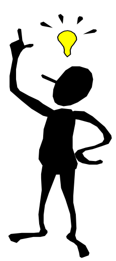
  - **M&E Balances, Second Law, Stoichiometry**

  - **What affects the key variables?**

  - **Could “normal” plant variation cause this behavior?**

  - **Causality, what came first? What was cause?**

## CLASS EXAMPLE



**Let’s determine relevant causal relationships.**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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CAUSE $\xrightarrow{\text{Time}}$ EFFECT

Heater outlet temperature

Feed flow

Feed tempera-ture

↑↓ = ?

Which direction would cause the effect?

??

What other causes influence the effect?

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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4. Plan
5. Implement
6. Evaluate

- **Check information and data!!!**
  - Is the temperature actually decreasing?
  - Is fuel actually increasing?
  - What <u>principles</u> can be used to check data?

- **Fundamental Balances**
- **Duplicate sensors on the same variable**
- **Consistency in rate processes**
  - pressure and flow
  - temperatures in heat transfer
- **Consistency in equilibrium process**
  - temperature and pressure in equilibrium process
- **Trends of related variables**
  - temperature and compositions in reactor

# PROCESS TROUBLESHOOTING

1. Engage

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- **Check information and data!!!**

  - Is the temperature actually decreasing?
  - Is fuel actually increasing?
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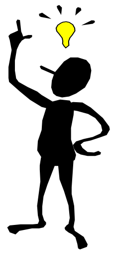
## CLASS EXAMPLE



How can we verify the data and information in the original problem statement?

# PROCESS TROUBLESHOOTING

1. Engage

2. Define

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6. Evaluate

- **Check information and data!!!**
  - Is the temperature actually decreasing?
  - Is fuel actually increasing?
  - What <u>principles</u> can be used to check data?

1. Temperature sensors for consistency, especially TC-1 and T4, which measure the same variable.
2. Flows FC-1 and F7 should be nearly the same.
3. Level L1 should be decreasing and Level L2 increasing.
4. Valve openings (signal to valves) for air and fuel should be "typical" for the value of F1.

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
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- **Relevant changes (maintenance, etc.)**

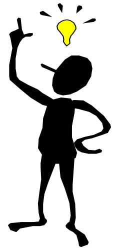
  **We should consider the time sequence in trouble shooting; however, a time sequence does not <u>prove</u> cause-effect.**

- **Startup (equipment first placed in service)**

  **We must consider a wider range of root causes when equipment is being started up.**

- **Trends**

  **-What is direction and rate of change of variables?**



**Let's explore these issues in the class example.**

# PROCESS TROUBLESHOOTING

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## CLASS EXERCISE

- **Relevant changes**

  a. Calibrated T7 and an instrument in another plant

  b. Changed feed tank required opening/closing block valves

- **Startup -** not applicable

- **Trends**

  a. For a long time, the TC-1 seemed to function, holding T near its set point

  b. The feed flow is increasing.

  c. Very recently, TC-1 is decreasing rapidly

  d. Very recently, F2 is increasing rapidly

# PROCESS TROUBLESHOOTING

1. Engage

2. Define

3. Explore

4. Plan

5. Implement

6. Evaluate

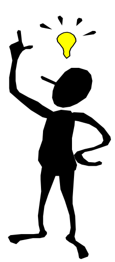
- **What is known and what is opinion?**

  **We must consider the statements of others. We should seek validation for the statements.**

- **Use guidelines and experience factors**

  **We will build these throughout our careers.**

  **- How does data compare with typical range?**
  **- Is that a typical pump outlet pressure?**
  **- What is a typical approach temperature?**
  **- What have we learned from prior faults?**



**Let’s complete building our understanding of the class example with these issue.**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## CLASS EXERCISE

- **What is known and what is opinion?**

  **Known**
  **Data plotted**
  **Feed tank changed (Was it? Was it done correctly?)**
  **T7 calibrated**

  **Opinions**
  **An unusual smell is present**
  **The cause is the stack damper**

- **Use guidelines and experience factors**

  **a. Are the values of the process variables typical?**
  **b. How long does the TC-1 vary before it "settles down" after a flow change**
  **c. What is a typical disturbance to TC-1?**

# PROCESS TROUBLESHOOTING

1. Engage

2. Define

3. Explore

4. Plan

5. Implement

6. Evaluate

"The solution to a process problem isn't found by sitting behind your desk, but by going to the plant and carrying out tests and evaluating the data."

by Laird, et al, Chem. Engr. Progress, (2000)

We have to analyze the initial data and formulate **working hypotheses**. These hypotheses give us a basis for investigations: they **focus** our investigations.

# PROCESS TROUBLESHOOTING

**Brainstorm causes** **Support/Neutral/disprove**

1. **Engage**
2. **Define**
3. **Explore**
4. **Plan**
5. **Implement**
6. **Evaluate**

| WORKING HYPOTHESES | INITIAL EVIDENCE (**S**upport, **D**isprove, **N**eutral) | | | | | DIAGNOSTIC ACTIONS (**S**upport, **D**isprove, **N**eutral) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | A | B | C | D |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**New, diagnostic actions**

**Consider time, cost, and sequence.**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## STEPS IN "PLAN"

A. Brainstorm possible root causes that might explain the initial evidence

B. Carefully compare the candidate hypotheses with the initial data and disprove hypotheses, if possible.

C. Develop a list of diagnostic actions that will have different outcomes for each remaining working hypothesis.

D. Order the diagnostic actions according to following: (1) high impact for reducing hazards, (2) low cost and (3) short time.

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## GENERATING THE CANDIDATE ROOT CAUSES

**Challenge the conventional wisdom**

- Do not be confrontational
- based on principles
- propose diagnostic action

**XXXX just could not happen.**

- Blocked pipe
- False measurement
- Change in equipment performance
- Change is conversion

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

**Brainstorm causes** **Support/Neutral/disprove**

| WORKING HYPOTHESES | INITIAL EVIDENCE (**S**upport, **D**isprove, **N**eutral) | | | | | DIAGNOSTIC ACTIONS (**S**upport, **D**isprove, **N**eutral) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | A | B | C | D |
| | | | | | | | | | |

**How do we know the entries: hypotheses, initial evidence and diagnostic actions?**

**They are based on the <u>understanding</u> developed during the "Explore" step, which is crucial for good trouble shooting.**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

**Brainstorm causes** **Support/Neutral/disprove**

| WORKING HYPOTHESES | INITIAL EVIDENCE (**S**upport, **D**isprove, **N**eutral) | | | | | DIAGNOSTIC ACTIONS (**S**upport, **D**isprove, **N**eutral) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | A | B | C | D |
| | | | | | | | | | |

**CLASS EXAMPLE**

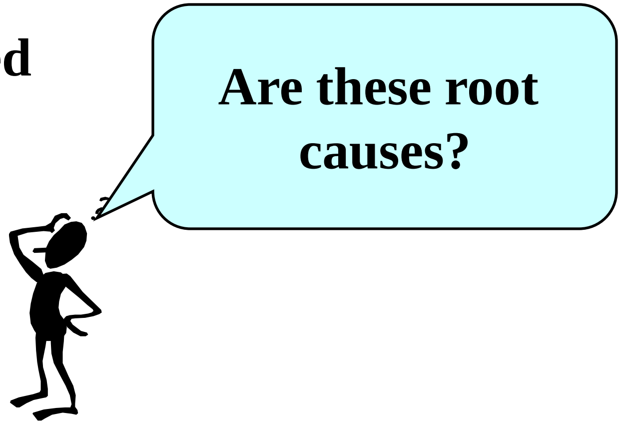
- **Develop a set of working hypotheses for the fired heater problem.**
- **Evaluate each using the initial evidence**

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## LIST OF TYPICAL WORKING HYPOTHESES (not necessarily complete)

- TC-1 control loop is unstable
- Packed bed reactor is plugged
- TC-1 sensor is faulty (reading lower that actual T)
- Fuel valve 300 is faulty
- Feed tank is running dry, causing vortex
- Stack damper is too far closed
- Feed flow rate is too high



# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## Use current information to differentiate among candidates

Does initial evidence support, is it neutral, or does it disprove?

Remember that initial evidence is subject to errors, for example, a sensor could be faulty or an opinion could be wrong.

This thought process will help to idenify diagnostic actions to complete trouble shooting.

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## Diagnostic Actions to differentiate among remaining candidates

**Good approaches**

- Specific and designed to test hypothesis
- Confirm data & information
- Compare with recent/typical data
- Do small experiments

- Variables can be measured
- Seek confirming information
- Retrieve useful historical data
- Analyze cause-effects

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

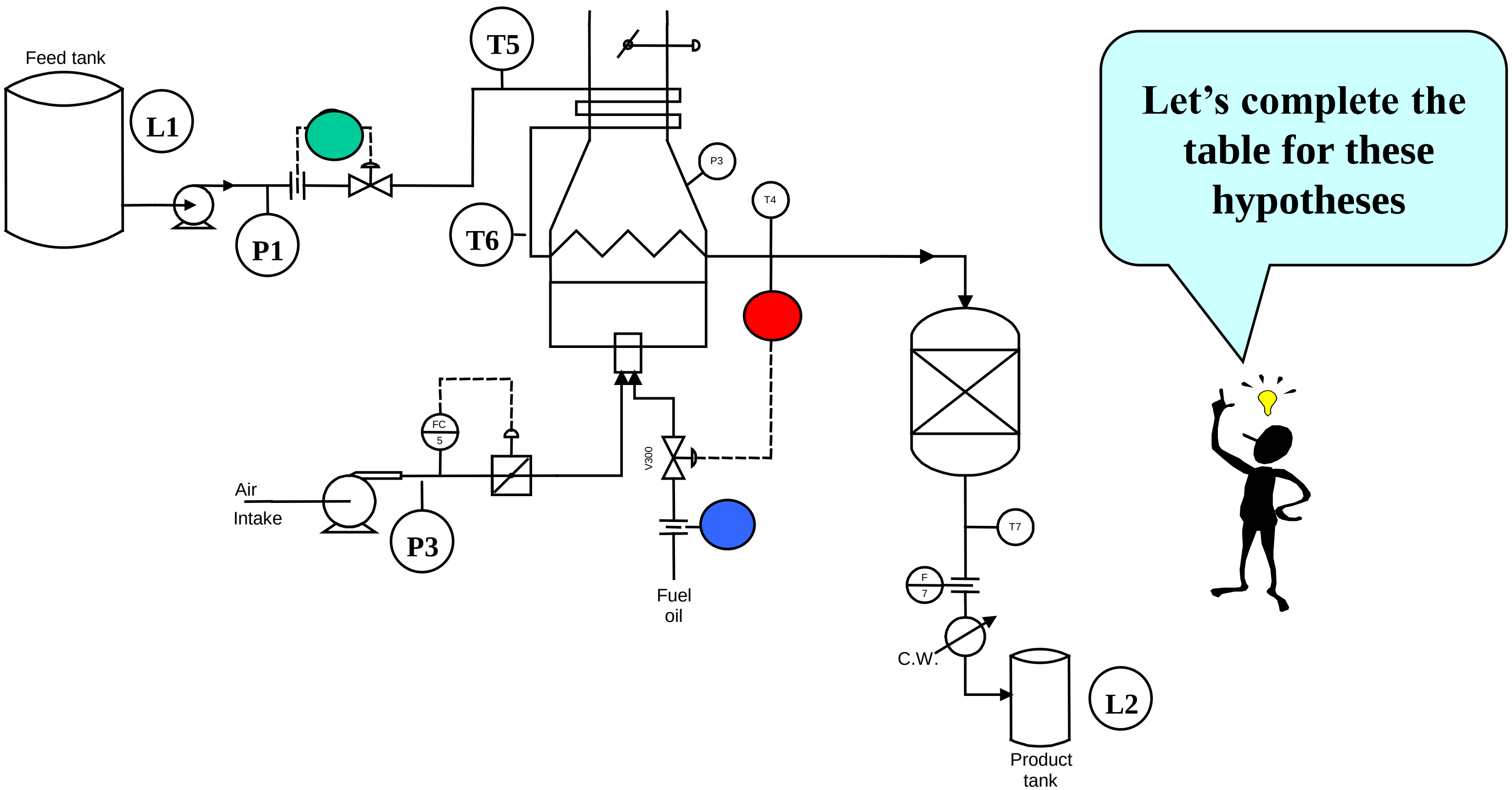
## Diagnostic Actions

**Poor Actions**

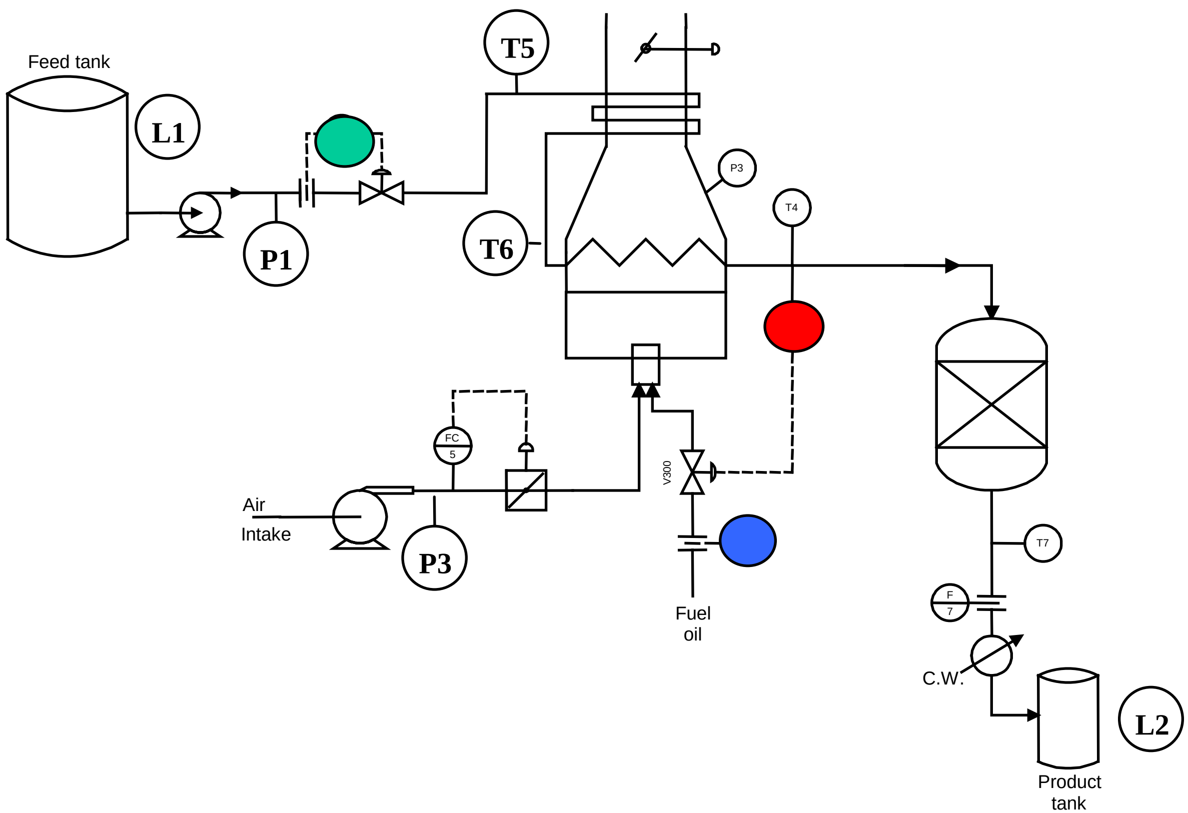
- "Check the valve"
- "What is the heat transfer coefficient?"
- "What is the fuel temperature?"
- "Shutdown plant and open reactor"

**These actions/questions are too vague or cannot be done. How would you perform the action and provide the results to an engineer?**

| Hypothesis | Initial information | Diagnostic Action |
|---|---|---|
| **TC sensor drift** | | |
| **Fuel valve is stuck open** | | |
| **Feed rate causing T decrease (TC too slow)** | | |



| Hypothesis | Initial information | Diagnostic Action |
|---|---|---|
| T sensor drift | Neutral | Check with temperature at exit of reactor |
| Fuel valve is stuck open | Disprove (Temperature would increase) | Place flow controller in manual and make small change to controller output |
| Feed rate causing T decrease (TC too slow) | Disprove (previous changes were controlled) | _______________ |



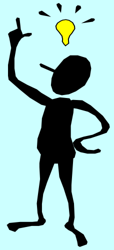
# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

Brainstorm causes    Support/Neutral/Disprove

| WORKING HYPOTHESES | INITIAL EVIDENCE (Support, Disprove, Neutral) | | | | | DIAGNOSTIC ACTIONS (Support, Disprove, Neutral) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | A | B | C | D |
| | | | | | | | | | |

## CLASS EXAMPLE



- Develop a set of diagnostic actions.
- Continue until the root cause has been identified.

# PROCESS TROUBLESHOOTING

## EVALUATE THE WORKING HYPOTHESES

| Working hypothesis | Initial data (S/N/D) |
|---|---|
| TC-1 unstable | N, transient could be start of large oscillation |
| Packed bed plugged | D, flow appears normal in F1 (and F7) |
| TC-1 sensor low | N, actual temperature could be high |
| Valve 300 faulty | D, the fuel flow is increasing |
| Feed tank low | D, the feed flow is normal |
| Stack damper closed | S, could affect the combustion |
| Feed flow rate too high<br>This is not a root cause.  Let's assume that the proposed root cause is not enough fuel | N, fuel valve not fully opened |

***S = Support, N = Neutral, D = Disprove***

# PROCESS TROUBLESHOOTING

## EVALUATE THE WORKING HYPOTHESES

| Working hypothesis | Diagnostic data (S/N/D) |
|---|---|
| TC-1 unstable | Place controller TC-1 in maual and increase controller output slowly |
| Packed bed plugged | N/A |
| TC-1 sensor low | Compare the temperatures from T4 and T7 |
| Valve 300 faulty | N/A |
| Feed tank low | N/a |
| Stack damper closed | Increase the damper opening |
| Feed flow rate too high<br>This is not a root cause.  Let's assume that the proposed root cause is not enough fuel | N/A |

***S = Support, N = Neutral, D = Disprove***

# PROCESS TROUBLESHOOTING

1. Engage

2. Define

3. Explore

4. Plan

5. Implement

6. Evaluate

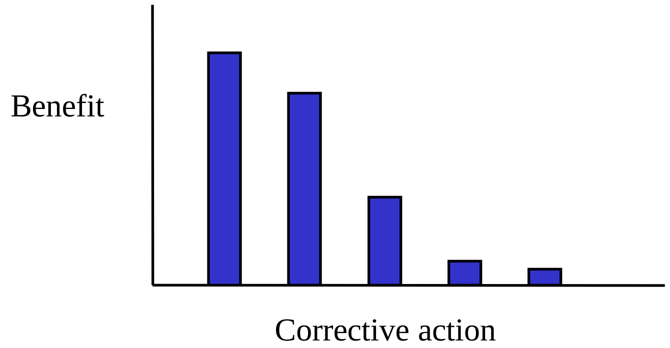
## Do it!

**Many actions may be possible. We select those justified by benefits.**

**A Pareto plot provides a visual display of relative benefits.**

**PARETO PLOT**

**Estimate the benefit from each corrective action, and implement those justified.**



# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

**Brainstorm causes** **Support/Neutral/disprove**

| WORKING HYPOTHESES | INITIAL EVIDENCE (**S**upport, **D**isprove, **N**eutral) | | | | | DIAGNOSTIC ACTIONS (**S**upport, **D**isprove, **N**eutral) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | A | B | C | D |
| | | | | | | | | | |

**We will continue diagnostic actions until only one hypothesis remains that has not been disproved. At that point, we will generally conclude that the remaining hypothesis is true.**

**We will call it the "root cause".**

**Note that we have not proved the hypothesis; we have not disproved it.**

# PROCESS TROUBLESHOOTING

1. Engage

2. Define

3. Explore

4. Plan

5. Implement →

6. Evaluate

## Do it!

### Achieve the

**Initial state quickly**

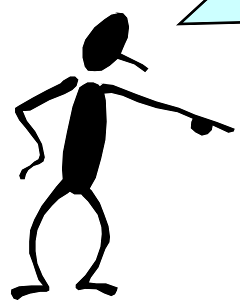
- Return to safe operation
- Acceptable product quality
- Protect process equipment

**Final state reliably**

- Efficient/profitable operation
- Desired production rate, if feasible
- Achieved without undue monitoring

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate



We typically will <u>NOT</u> complete Pareto charts or Must/Want tables when solving a plant problem.

**But, we need to use these methods without formal documentation!**

| | | Possible solution scores | | |
|---|---|---|---|---|
| **Musts** | | 1 | …… | 4 |
| 1. Safety | | **Y** | N | Y |
| 2. Meet production contracts | | N | Y | Y |
| | | | | |
| **Wants** | weight | | | |
| 1. DCF > 15% | 8 | | | 10 |
| 2. Energy < 2 GJ/kg | 5 | | | 7 |
| | | | | |
| | | | | |
| Total weighted score | | | | 115 |

# CLASS EXAMPLE

1. Engage

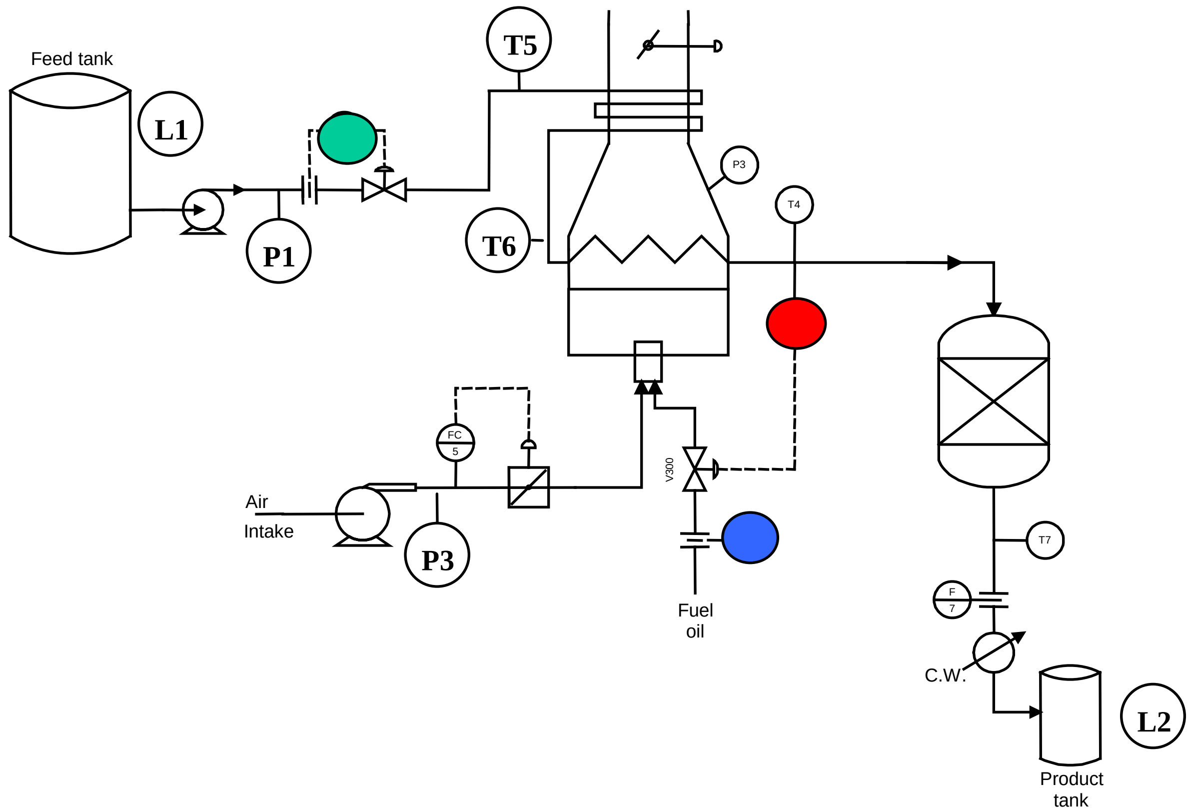
2. Define

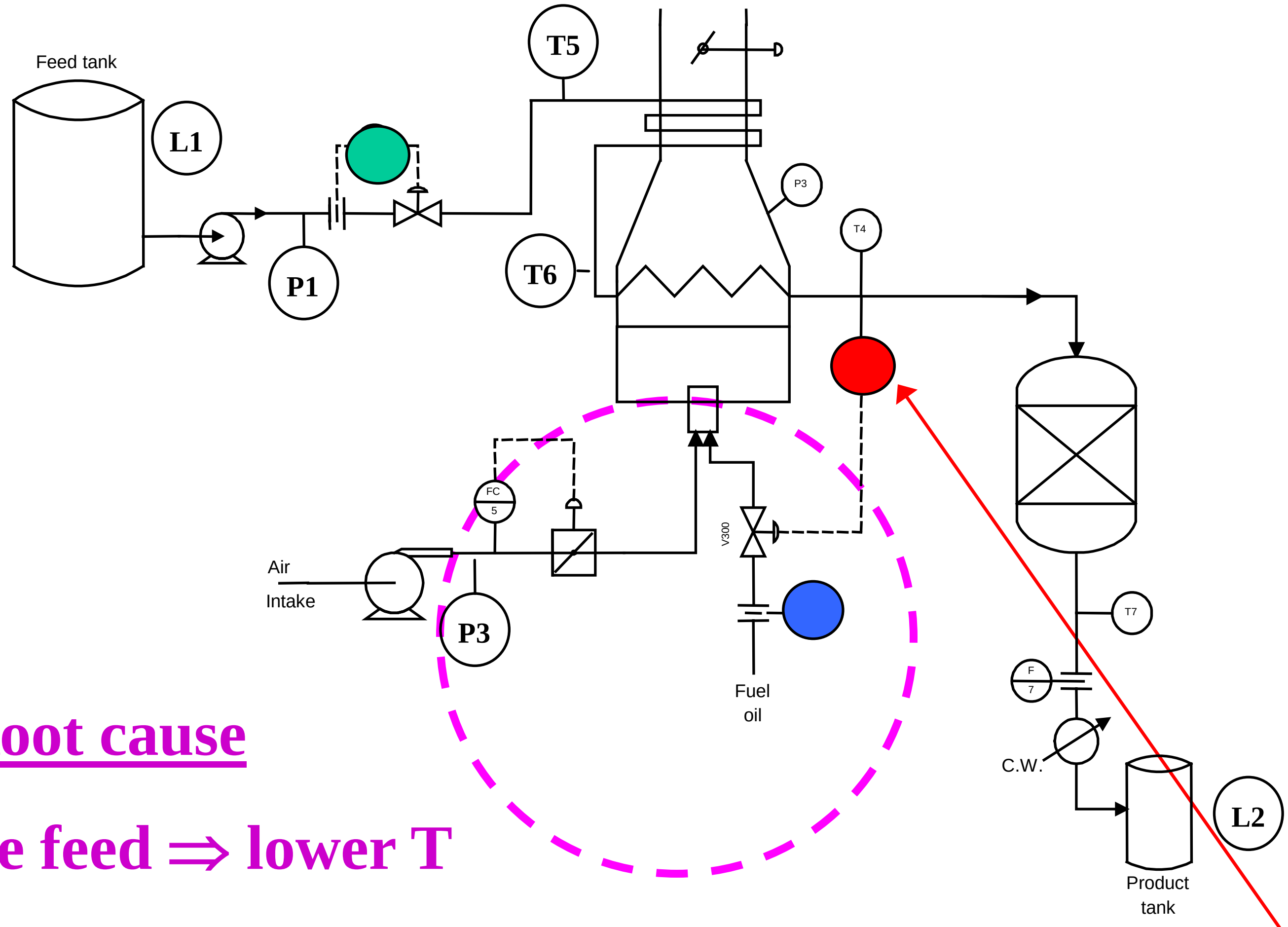
3. Explore

4. Plan

5. Implement

6. Evaluate




## Root cause

- Increase feed ⇒ lower T
- Lower T ⇒ controller increases fuel
- Decreased air/fuel (air=constant)
- Insufficient air ⇒ lower T

## Key Concept

**The process gain in the feedback loop changed sign!**

# PROCESS TROUBLESHOOTING

1. Engage

2. Define

3. Explore

4. Plan

5. Implement

6. Evaluate

## Achieve the first desired state rapidly!

- Place TC-1 in manual, stop the increase of fuel to heater
- Close fuel valve (v300) until T-1 starts to increase

  (Note: Do not increase the air to the fuel rich heater environment!)
- Ensure that oxygen is in excess in flue gas (no smoke, view flame, sample flue gas to lab)
- Place TC-1 in auto
- Continue to increase feed, but increase air flow before feed! Monitor stack gas.

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

## Achieve the final desired state.

- Install on-stream flue gas analyzer
- Set desired excess oxygen by experience to be 1.5-2%
- Provide low oxygen alarm (typical value of 1%)
- Train operators to adjust air flow to achieve desired excess oxygen
- Automate the control of oxygen by adjusting the air flow rate.  This would be a cascade control design.

# PROCESS TROUBLESHOOTING

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

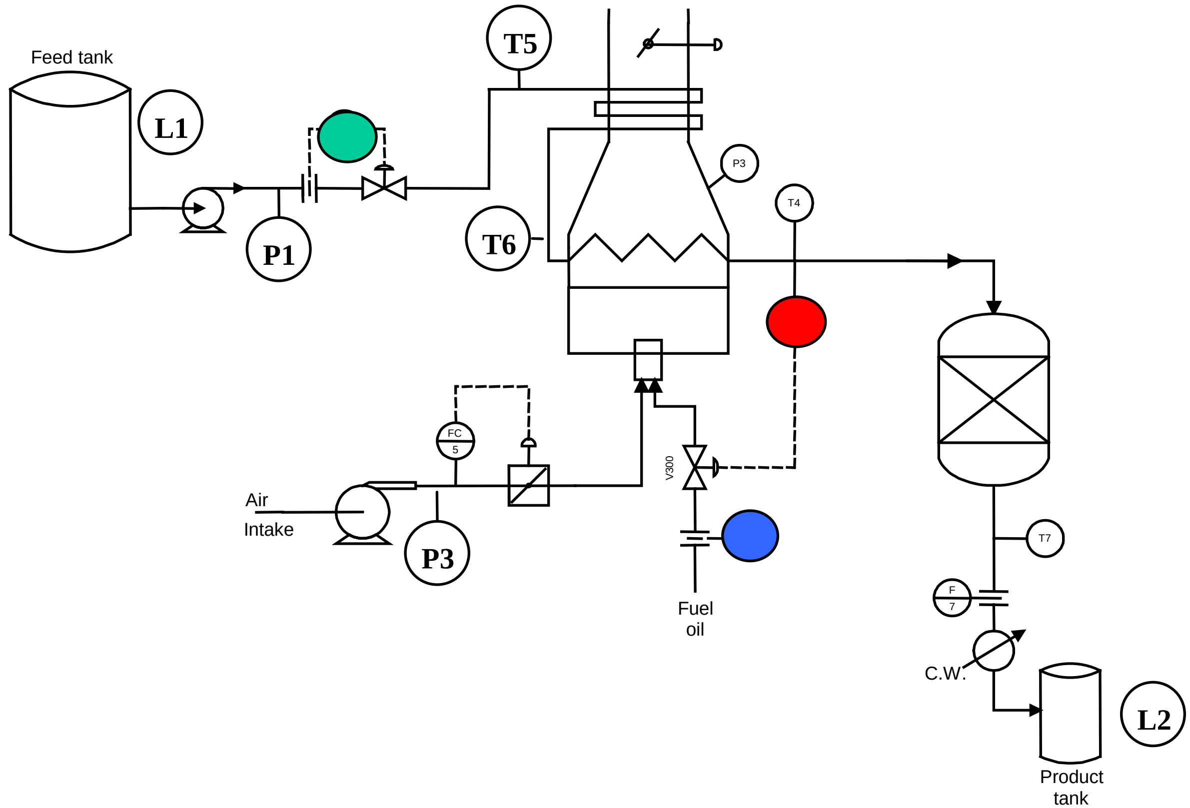
## Create a "Lookback"

- Did we solve the Root Cause?
- Did we generate more confirming information?
- How can we prevent in the future
  - training
  - monitoring programs
  - modifications to current plant equipment &/or procedures
  - design guidelines for future plants
- Enhance our personal experience factors
- Check ethics and legal one more time

# CLASS EXAMPLE

1. Engage
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

Let's prepare a look back with steps to prevent future incidents

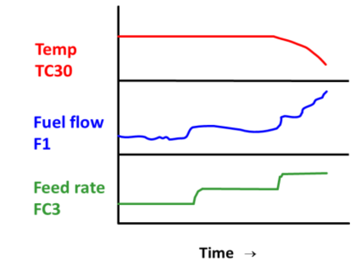


# Successful Troubleshooting Lesson

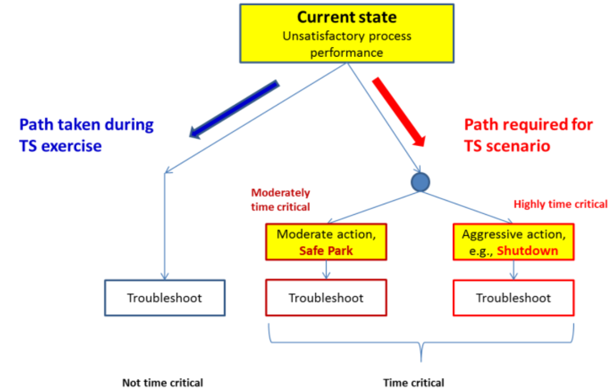
## Unsuccessful TS Practice

**We learned a lot, but the plant experienced a major hazard!**

- **We missed the time-critical situation**
- **Industrial operators and engineers would have extensive training to recognize and correct**
- **But, we are just learning and need more time. As we gain expertise, we will execute quickly.**




**The initial data that raised a concern about the process operation**



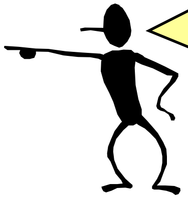

**Is it time-critical? The first major decision in the process states during Trouble Shooting**


Fired Heater after a fire-box explosion.

# PROCESS TROUBLESHOOTING

## SOME TYPICAL  STRATEGIES THAT DO NOT WORK

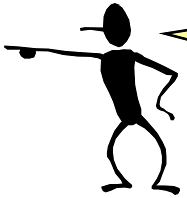
1. **If you don’t understand, guess.**



**It’s the pump, no!**
**It’s the valve, no!**
**It’s the pipe, no!**
**…..**
**…..**

2. **Confuse symptoms with root cause.**

3. **Get tunnel vision.**



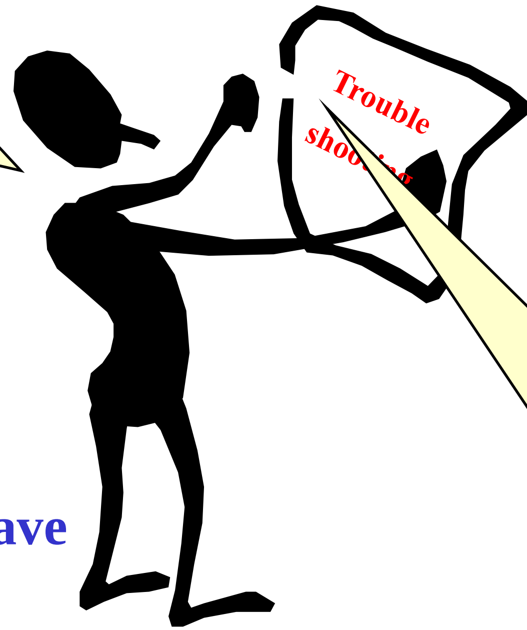
**It must be the pump.**
**But, the symptoms point away from the pump.**
**It’s the pump.**

4. **Accept all information as relevant and correct.**

# PROCESS TROUBLESHOOTING

## <u>Attitude Check</u>

**I hate trouble shooting. The forms are too long, I don't know enough about equipment, and I don't like the pressure.**



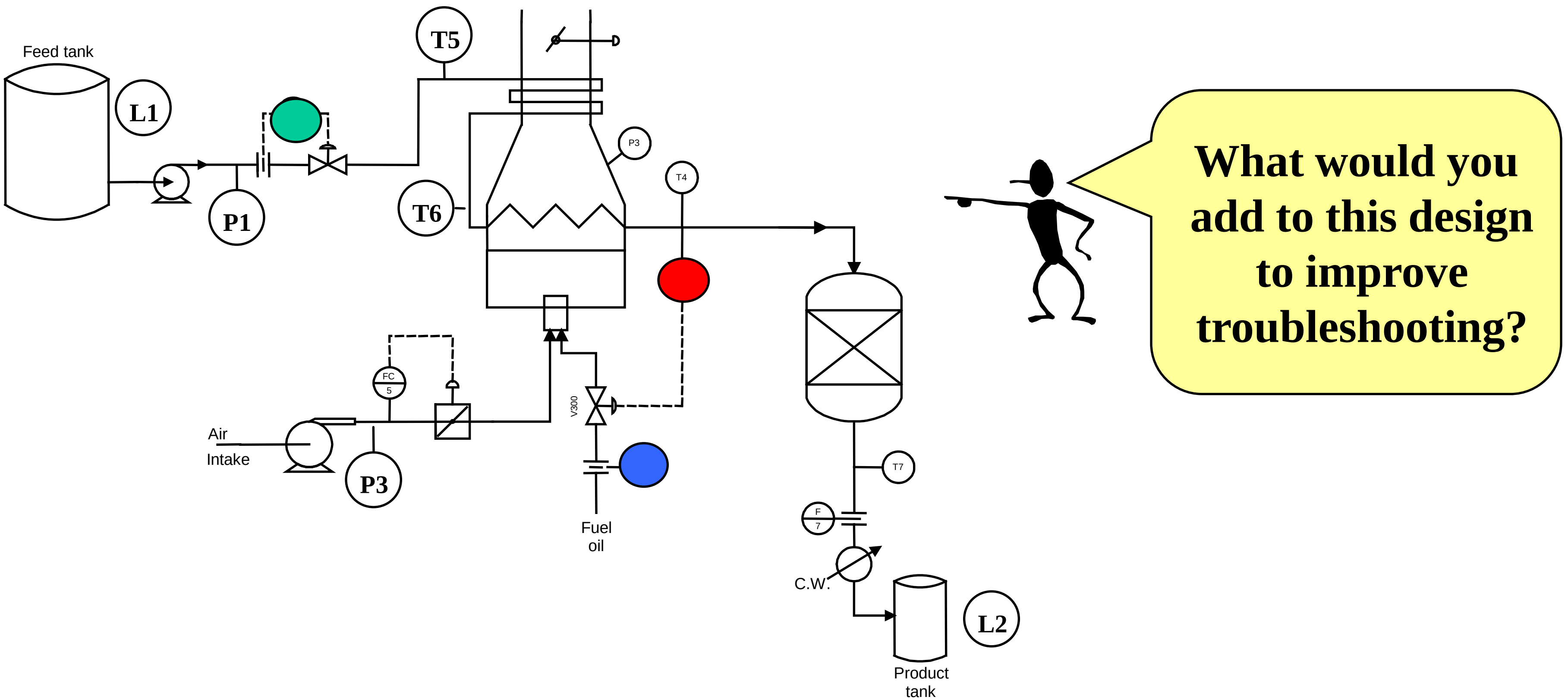

**Yeah, yeah, I know that I'll have to trouble shoot. I'll wait until it really matters.**

- **No memorization, you will have the form**
- **Good, "problem-based" way to learn about equipment**
- **Pressure, try when $$ matters!**

- **When it matters, we have to <u>produce immediately</u>.**

# PROCESS TROUBLESHOOTING

**Key additional lesson: We must build plants that can be monitored and diagnosed! This requires many extra sensors (local and remote), sample points for laboratory, and sometimes, visual observation (glass ports).**



# PROCESS TROUBLESHOOTING

## Further Steps to Refine Trouble Shooting Skills

- **Review attached table with enriching and detracting behaviors for a trouble shooter**
- **Skim references on the next slide and locate hints most helpful to you**
- **Perform the workshops included in this lesson**
- **Practice the trouble shooting method on problems you encounter in you studies (laboratory, independent research, operability project in this course, etc.)**

# References for Trouble Shooting

The following three resources provide excellent approaches and useful references for further study.


Fogler, H. Scott and Steve LeBlanc, *Strategies for Creative Problem Solving*, Prentice Hall PTR, Upper Saddle River, 1995.

Kepner, Charles and Benjamin Tregoe, *The New Rational Manager*, McGraw-Hill, New York, 1981.

**Marlin, Thomas *Chapter 9 Process Troubleshooting* in *Process Operability*, Published on-line at http://pc-education.mcmaster.ca/Operability/Operability_Home.htm (2013)**

Woods, Donald, *Problem Based Learning: How to Gain the Most from PBL*, Griffin Printing, Hamilton, Ontario, 1994.

**Woods, Donald, *Successful Trouble Shooting for Process Engineers*, Wiley VCH, Weinheim, 2006.**

Additional references:

Laird, D., B. Albert, C. Steiner, and D. Little, Take a Hands-0n Approach to Refinery Troubleshooting, CEP, 98, 6, 68-73 (June 2002)

## <u>Appendix A.  EXPLORE</u>: The crucial step, but the least well understood

- Develop a mental image of the problem

    Various levels of accuracy to screen ideas, "successive approximation"
    For example,
    - input/output only, no details of mechanisms within system
    - order of magnitude on system behavior
    - limits on behavior (second law, equilibrium, etc.)
    - typical results from similar calculations or data
    - simplified analysis (constant properties, perfect equipment, etc.)
    - detailed calculations (flowsheeting)
    - thorough data experimentation (see Chem. Eng. 4C03 for methods)

- Initially, remove some constraints from the problem.

    - If I could look at the catalyst surface, …
    - If I could know the actual rate of reaction, …
    - If I could look at the internal flows in the vessel, ….

- Be open to an unlikely (but not impossible) root cause

- Develop the "nothing happened" hypothesis.  Could the situation arise without a problem but with a fault in some data?  Is this really a problem?

- Take a risk with a "far out" idea

- Don't judge too soon

- Incubate your ideas.  If time permits, leave the TS challenge to perform other tasks.  Often, you will return with new perspectives and hypotheses.

## Appendix B. Extra topics for PLAN

Short term

- to move quickly to a safe and environmentally acceptable condition
- to avoid damage to equipment
- to maintain the plant in a condition to regain operation quickly (if possible)
- to further verify the diagnosis (if needed)
- to maintain product quality (if possible)
- to achieve as near as possible the desired production rate

Longer term

- to shutdown equipment, if needed for repair, safety, etc.
- to provide time for detailed analysis and calculations or laboratory investigations
- to perform diagnosis possible only on plant after shutdown
- to improve the operating policy used by plant personnel
- to improve the maintenance policy of the plant
- to provide improved equipment for the plant

e. Continue to Trouble Shoot

- How can we monitor the solution to verify that the diagnosis was correct?
- How can we be alert for other potential problems?

f. Communicate and seek support and critiques from others

- Naturally, this depends on the time available and cost of the solution
- Do not relate the history of your problem solving; give a summary of the situation, diagnosis table, basis for root cause diagnosis and proposed solution.
- Clearly relate the implications for safety, environment, product quality, production and cost
- Be concise
- Be honest; explain any remaining uncertainty

g. When agreement has been reached and authority given

- Document the analysis and solution clearly and precisely
- Provide a clear plan of execution with measurable check points

## Appendix C. Extra topics for EVALUATE

a. Did we solve the problem? Compare the results with predictions

b. What are the beneficial collateral consequences of solving the problem?
   - How can we be sure to sustain these?

c. What are potential problems caused by your solution (ethical, legal, safety, profit etc.)?

   - Prepare corrective actions if they should occur

d. How can we prevent this problem from recurring?

e. How can you help your colleagues from your learning experience?

f. How can we add to our experience factors?

g. How can we identify a similar potential problem at an early stage in its development?

   Engineers establish process **monitoring and diagnosis** procedures that are performed routinely to provide early indication of plant performance. How can the problem solving experience be used to improve monitoring of this plant? For example,

- Improved training of operating personnel
- Additional sensor(s) or periodic laboratory analysis
- Additional calculations to summarize plant performance (yields, energy/kg, efficiency, heat transfer equipment, etc.)
- Local monitoring of equipment
- Improved maintenance procedures that are performed immediately upon a specific condition in the plant

# TROUBLE SHOOTING WORKSHOP

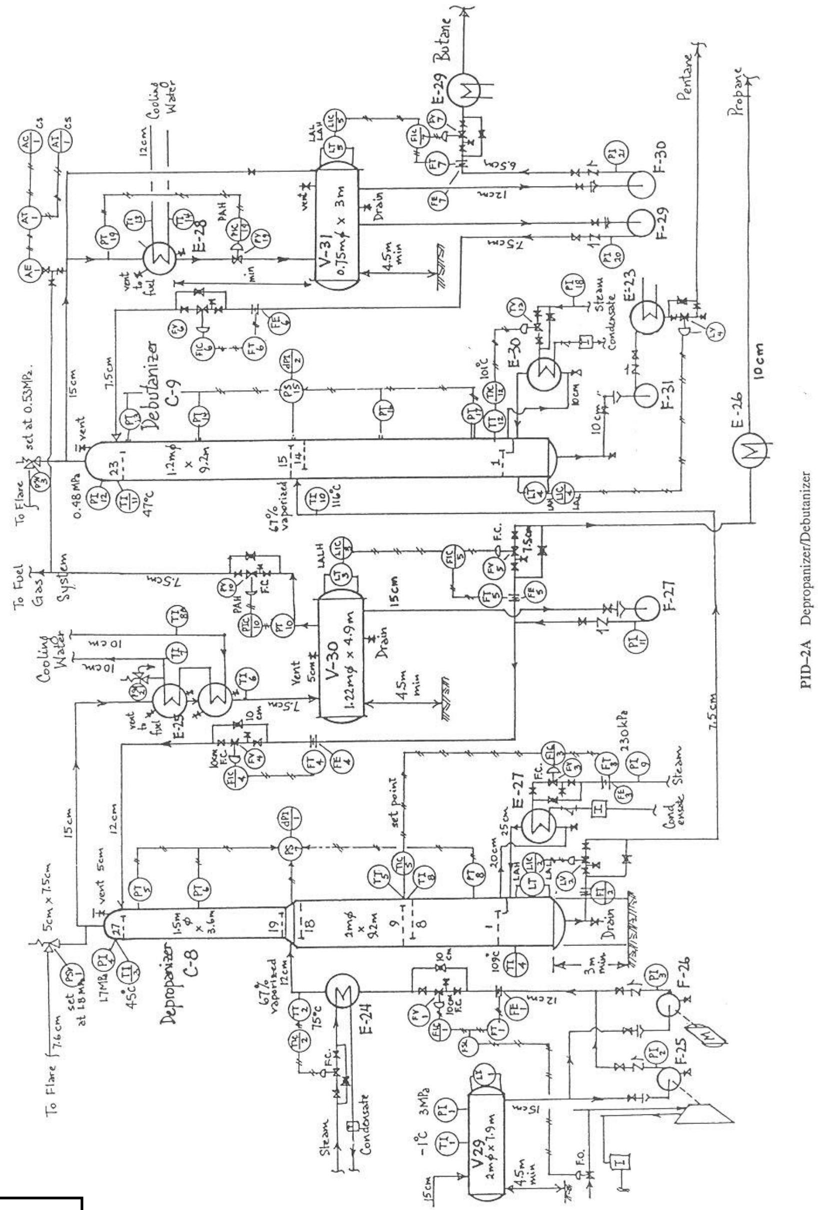
**We will improve our TS skills by applying the standard method to a process with which we are all familiar, distillation. The process is given in the following figure. Note that the distillation process includes heat transfer, fluid flow, process control and safety equipment.**

**We cannot compartmentalize our knowledge when solving realistic problems!**

**Four problems are provided. You will work in groups to solve these. The instructor will provide feedback to your questions and diagnostic actions.**

# Two-distillation process used in the Trouble Shooting Workshop

- **Depropanizer**
- **Debutanizer**




*See larger copy in the lecture notes.*

## TROUBLE SHOOTING WORKSHOP EXERCISE 1

The new two-distillation tower plant in the figure was just started up today. It has been running well for several shifts. The operators have been slowly increasing production rate, and they have achieved 80% of the design feed rate to the tower.

Just one hour ago a new operator came on duty, and this operator changed the pressure at which the Depropanizer, C-8, is operated, raising the pressure by 0.1 MPa. She has also continued to very slowly increase the production rate.

About 10 minutes after the pressure was increased, the tray temperatures began to go crazy and the bottoms level started to decrease. The operator believes that the reboiler has “stopped heating”.

Everyone=s Christmas bonus depends upon a profitable plant startup. Better fix this problem, or you will need a loan to buy those Christmas presents!

## TROUBLE SHOOTING WORKSHOP EXERCISE 2

To be able to sell your products, your plant must obtain ISO certification. (This ensures that the plant has consistently enforced quality control procedures.) Your customer service engineer reports that one of the customers is dissatisfied with the butane product; you don't have more details. As a result, you have established a routine composition analysis of various streams in the depropanizer and debutanizer in the two-distillation process that has been operating for years.

The composition monitoring program has been operating for one week. The laboratory analyses indicate too much variability in the mole fraction propane in the bottoms of the depropanizer, C-8. For the last day, the mole fraction propane has been about 0.04, while the target is 0.015.

Before the new procedures, we never knew that we were operating the plant poorly, so no one cared! If you cannot obtain ISO certification, the company will not be able to sell products to the key customers.

Everyone is mad at you for finding the problem! You better solve this problem so that the plant can continue to operate and you are safe at work.

## TROUBLE SHOOTING WORKSHOP EXERCISE 3

The operation of the upstream process, which prepares the feed to the two-distillation tower process, is being modified to accommodate a new catalyst and modified raw material composition. The new upstream process has been operating for nearly a shift, and the two distillation towers seem to be functioning well. You note that some of the tray temperatures are different from before the change, but the product purities, as measured by special laboratory analysis, are very near their specifications. You are satisfied that all is well. You return to your office to eat that muffin that you purchased on the way to work this morning.

Just when you have brewed the coffee and heated the muffin in the microwave, the plant operator calls you. The high pressure alarm in the debutanizer is on, and the operator is worried that the safety valve will open. (You are never sure that it will close completely, so we don=t want it to open unless needed.) He thinks that the upstream change is the cause of the problem but doesn't give you a clear reason why.

You have not been working in this unit for long, so here is your chance to make friends with the operator. Let=s work with the operator to fix this problem!

# TROUBLE SHOOTING WORKSHOP EXERCISE 4

This two-distillation tower process was successfully started up in January, when a careful check indicated that the operation was very close to the design values.  You are sure of that because you worked 12 hours per day to check and double check everything.

In August, you are assigned the responsibility for this process.  You decide to take a careful look at the current operation.  Laboratory analysis of the depropanizer vapor product indicates a high loss of propane to the fuel system, 2.5 times the design value.

This loss of product to fuel is costing lots of money!  You want to find the cause fast – you would like to provide a solution as well as a problem to the plant manager.  Time to apply your trouble shooting skills!