MCMASTER UNIVERSITY

CHEMICAL ENGINEERING 4N04

PROCESSTROUBLE SHOOTING

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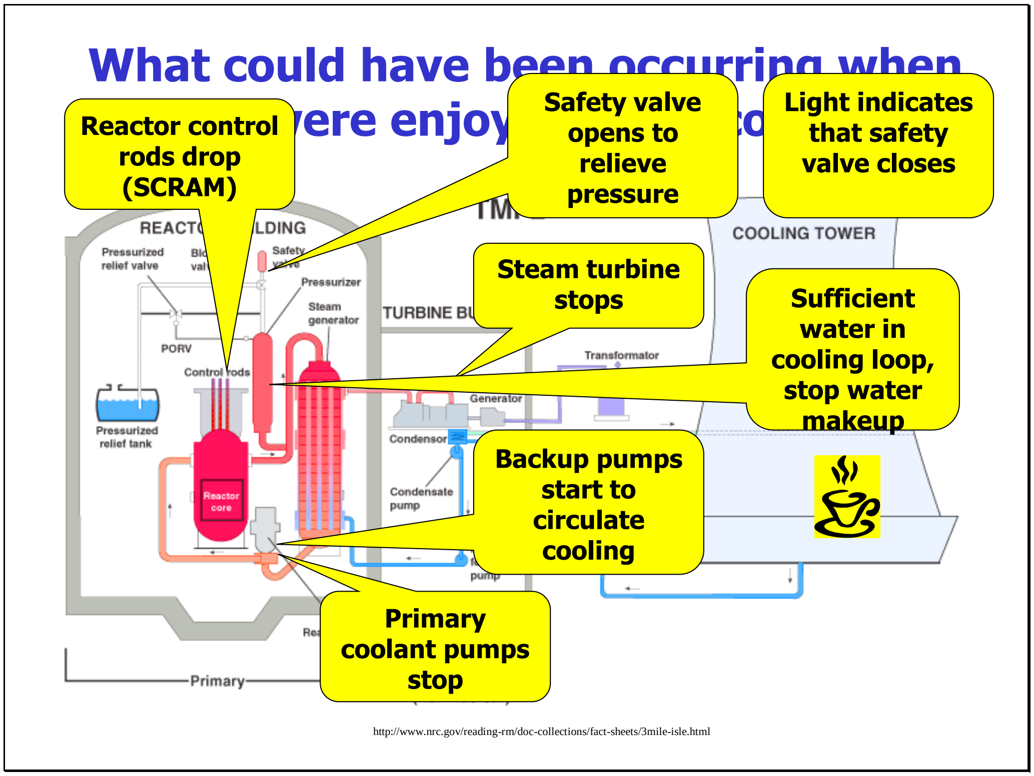

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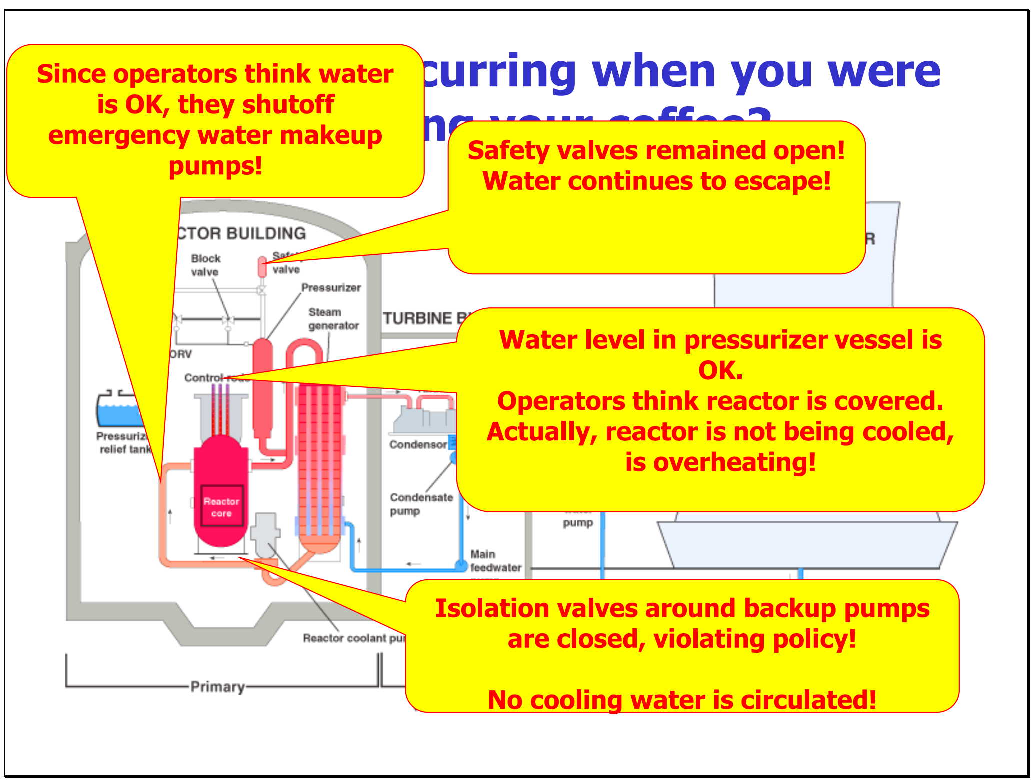

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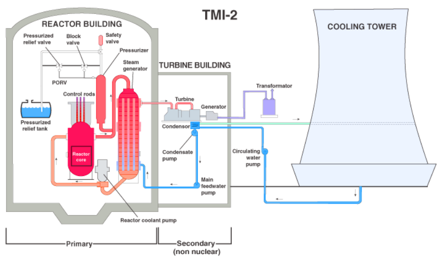
What is needed to prevent such incidents?

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



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

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

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Three Mile Island Worksheet

Design deficiencies	Operations deficiencies

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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 design plants - You must design so that others can monitor and diagnose
- If you manage plant operations – You will be troubleshooting
- If you are a consultant – No one calls you until something has gone wrong; you will be trouble shooting
- If you are interested in profit – Trouble Shooting is a profitable service to provide to customers

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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?"

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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**

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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

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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

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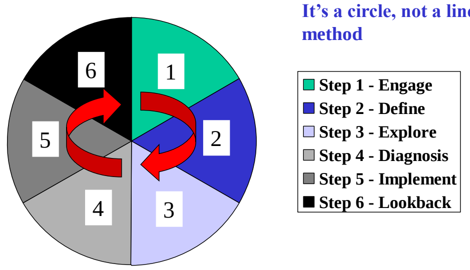
TROUBLE SHOOTING APPLIES THE SIX-STEP PROBLEM SOLVING METHOD

It's a circle, not a linear method



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

Trouble Shooting Worksheet

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 Diagnosis, 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

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

5. Do it : Implement solution 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

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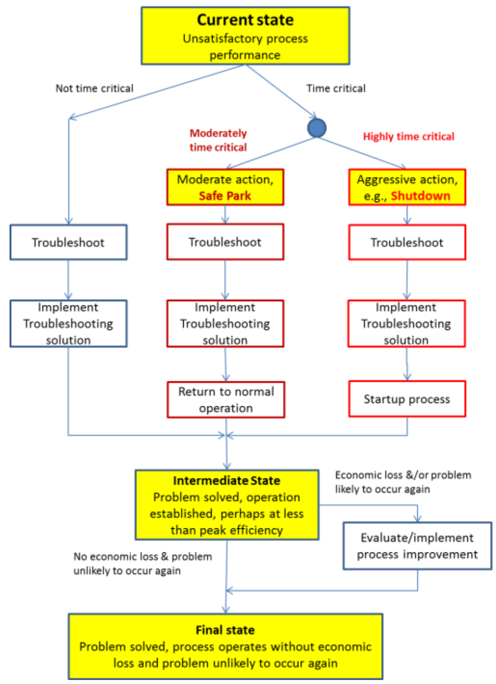
Process troubleshooting
(Considering time)

Maintain the process in a safe condition – ALWAYS!

- Not Time-critical
- Safe Park
- Shutdown

Reviewed initially and throughout the TS procedure



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PROCESS TROUBLESHOOTING

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

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.

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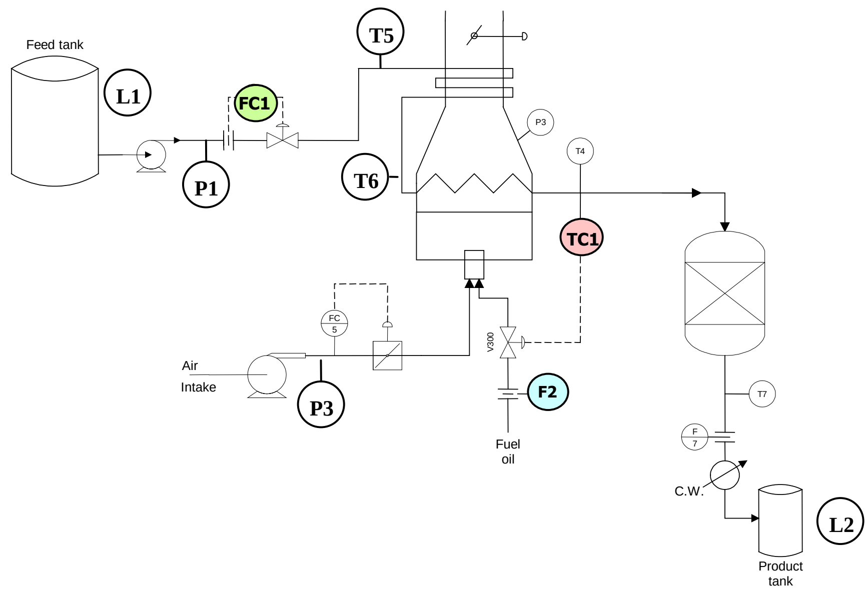
CLASS EXAMPLE: Let's discuss this process with preheat, packed bed reaction, and effluent cooling



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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.

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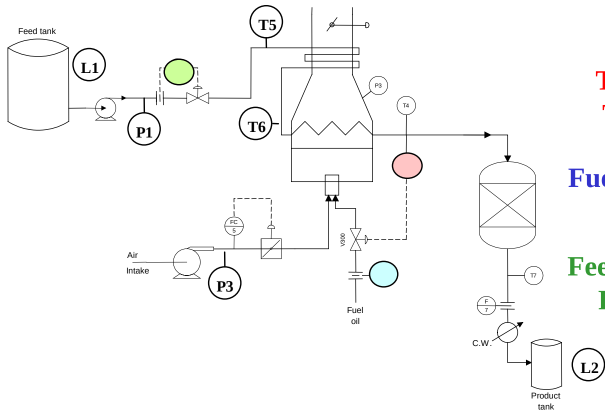
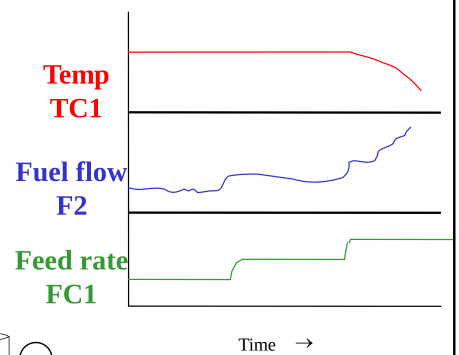
CLASS EXAMPLE: Trouble Shooting

The operator does not like these trends





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PROCESS TROUBLESHOOTING

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

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.

I want to, and I can!!

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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-$

- **Specific and Measurable**
- **Attainable**
- **Reliable**
- **Timely** (can be achieved in the appropriate time)
- **Safely**
- **$ = Cost-Effective**

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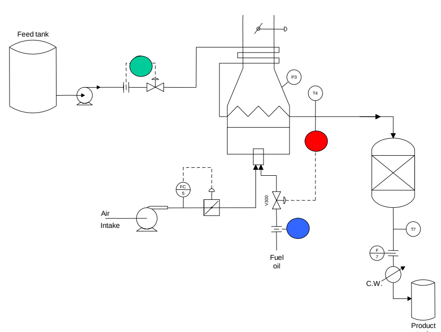
CLASS EXAMPLE

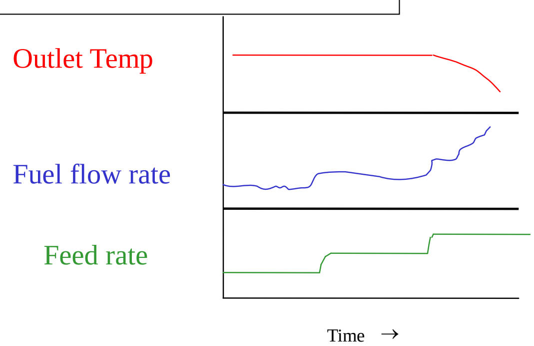
Should be:

Actually:

Initial state:

Final State:





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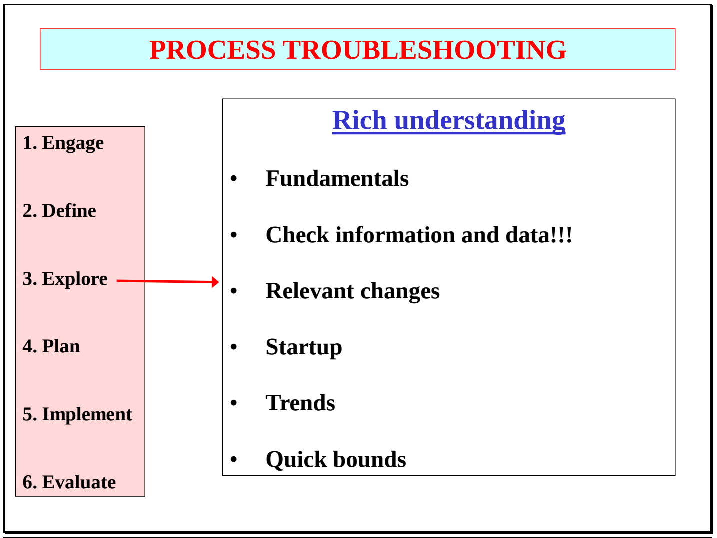

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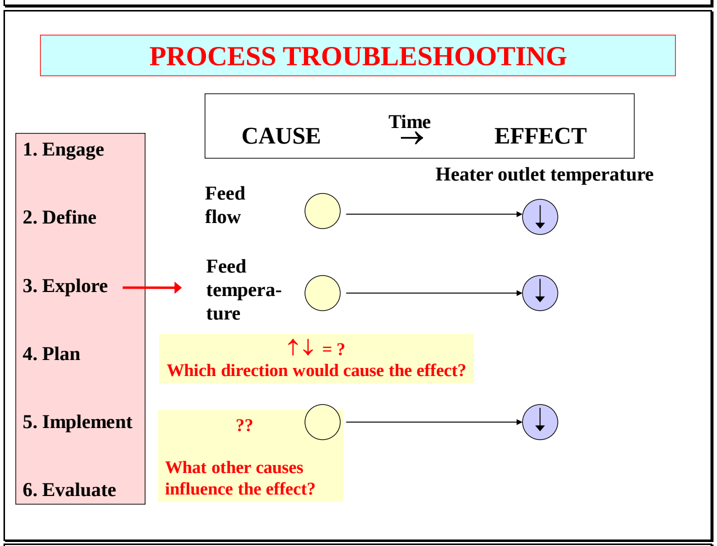

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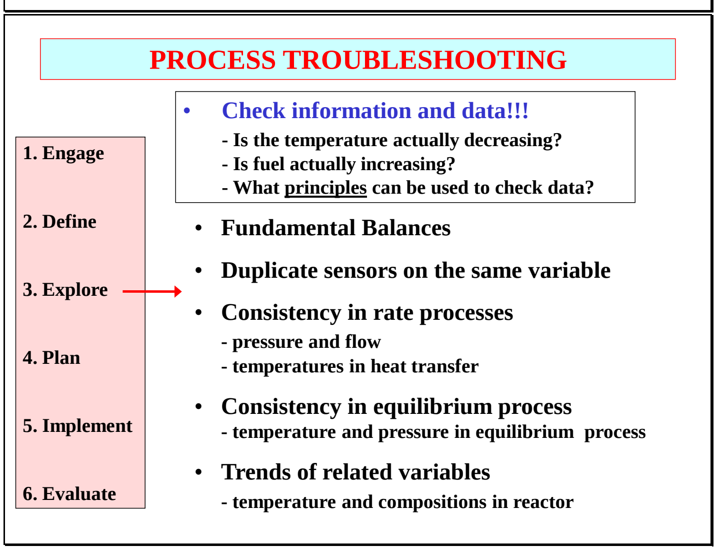

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PROCESS TROUBLESHOOTING

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

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

CLASS EXAMPLE

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

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PROCESS TROUBLESHOOTING

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

- **Relevant changes (maintenance, etc.)**

  We should consider the time sequence in trouble shooting; however, a time sequence does not prove 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.

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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.

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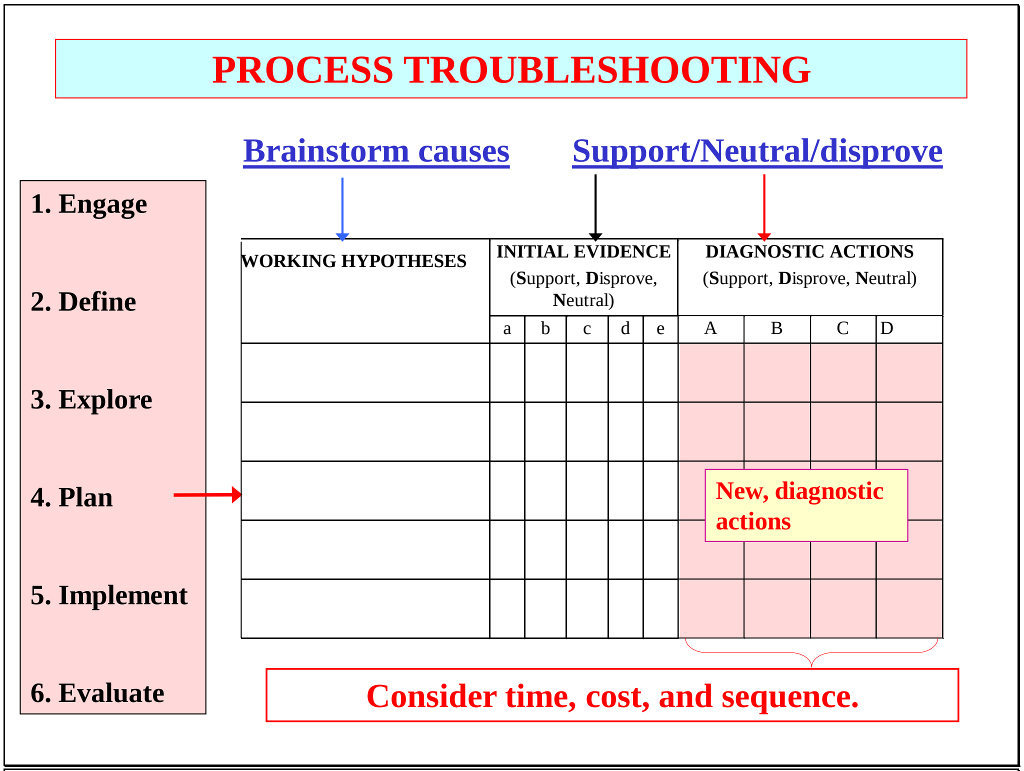

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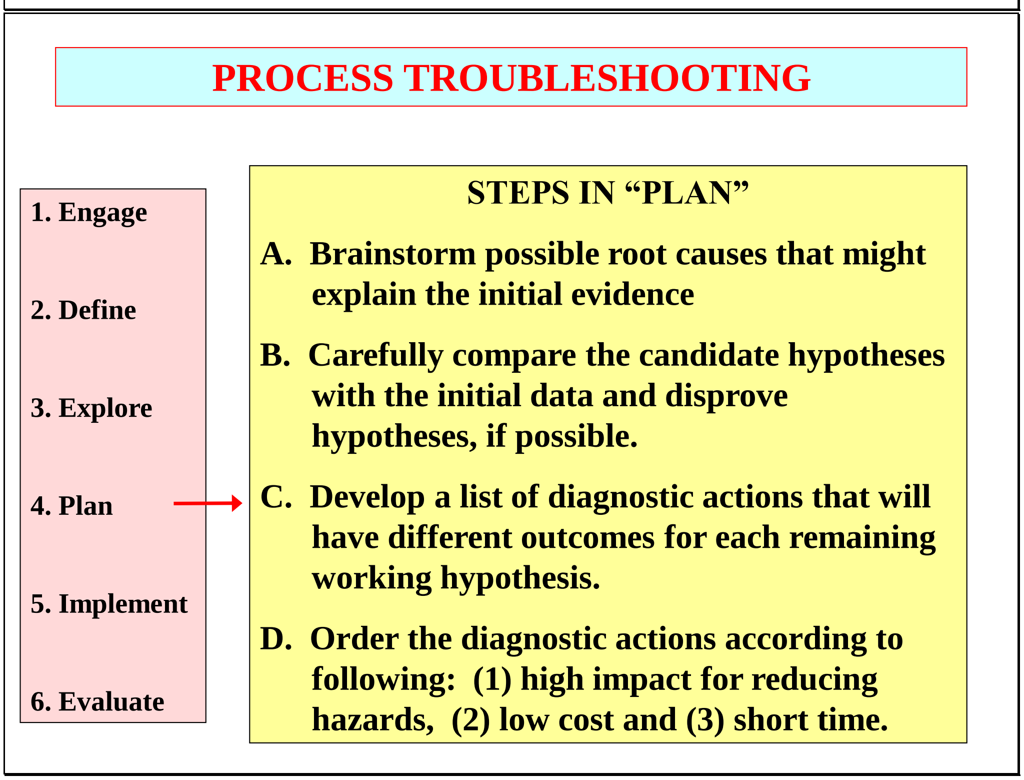

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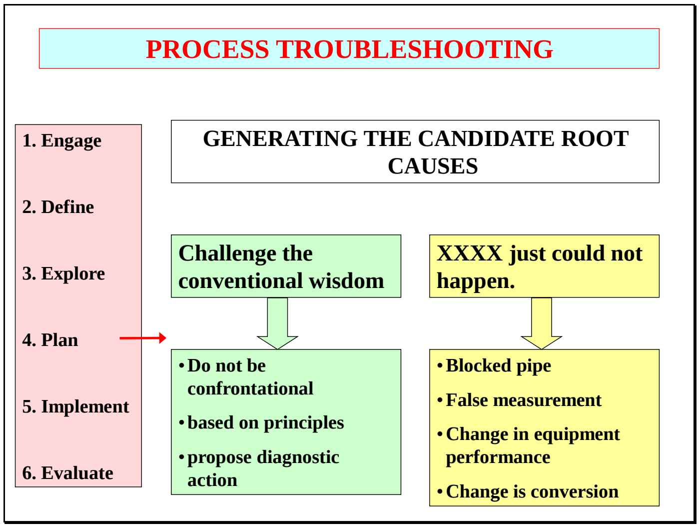

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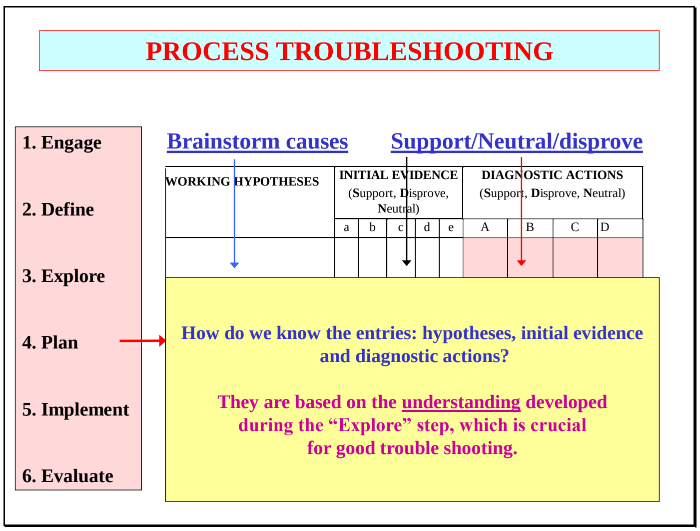

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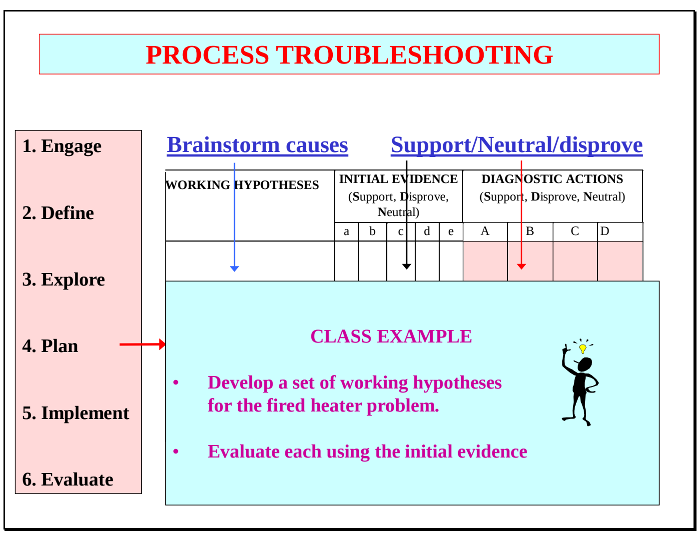

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PROCESS TROUBLESHOOTING

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.

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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

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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?

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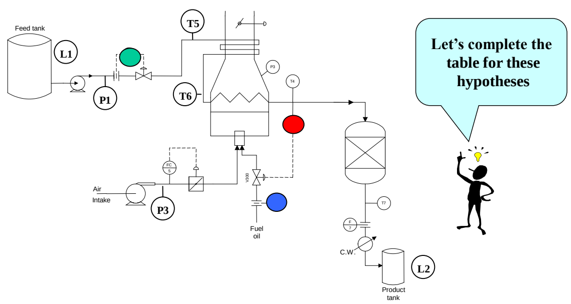
Hypothesis	Initial information	Diagnostic Action
TC sensor drift		
Fuel valve is stuck open		
Feed rate causing T decrease (TC too slow)		



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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.

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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

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.

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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

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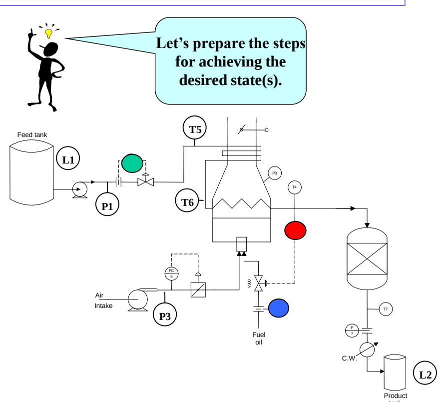
CLASS EXAMPLE

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



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PROCESS TROUBLESHOOTING

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

Achieve the first desired state rapidly!

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PROCESS TROUBLESHOOTING

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

Achieve the final desired state.

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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**

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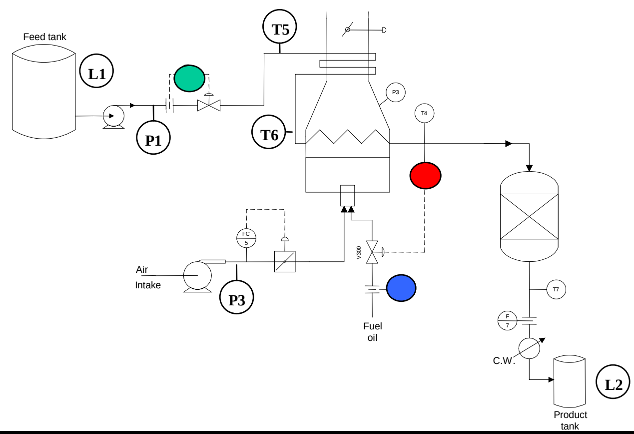
CLASS EXAMPLE

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



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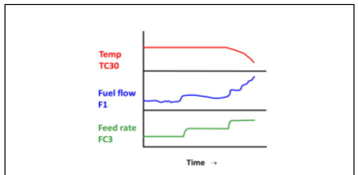
Successful Troubleshooting Lesson

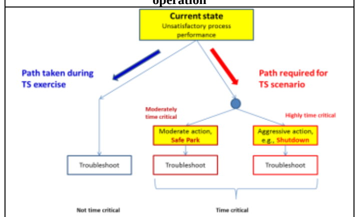
Unsuccessful TS Practice

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.

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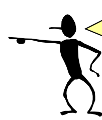
PROCESS TROUBLESHOOTING

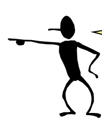
SOME TYPICAL STRATEGIES THAT DO NOT WORK

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.**

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PROCESS TROUBLESHOOTING

Attitude Check

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 produce immediately.

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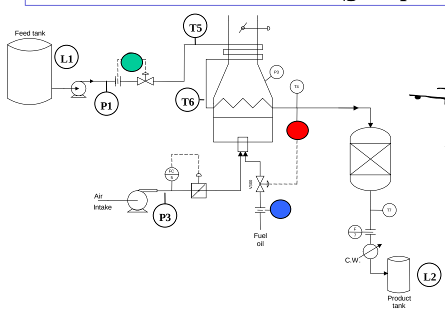
PROCESS TROUBLESHOOTING

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).



What would you add to this design to improve troubleshooting?

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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.)**

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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)

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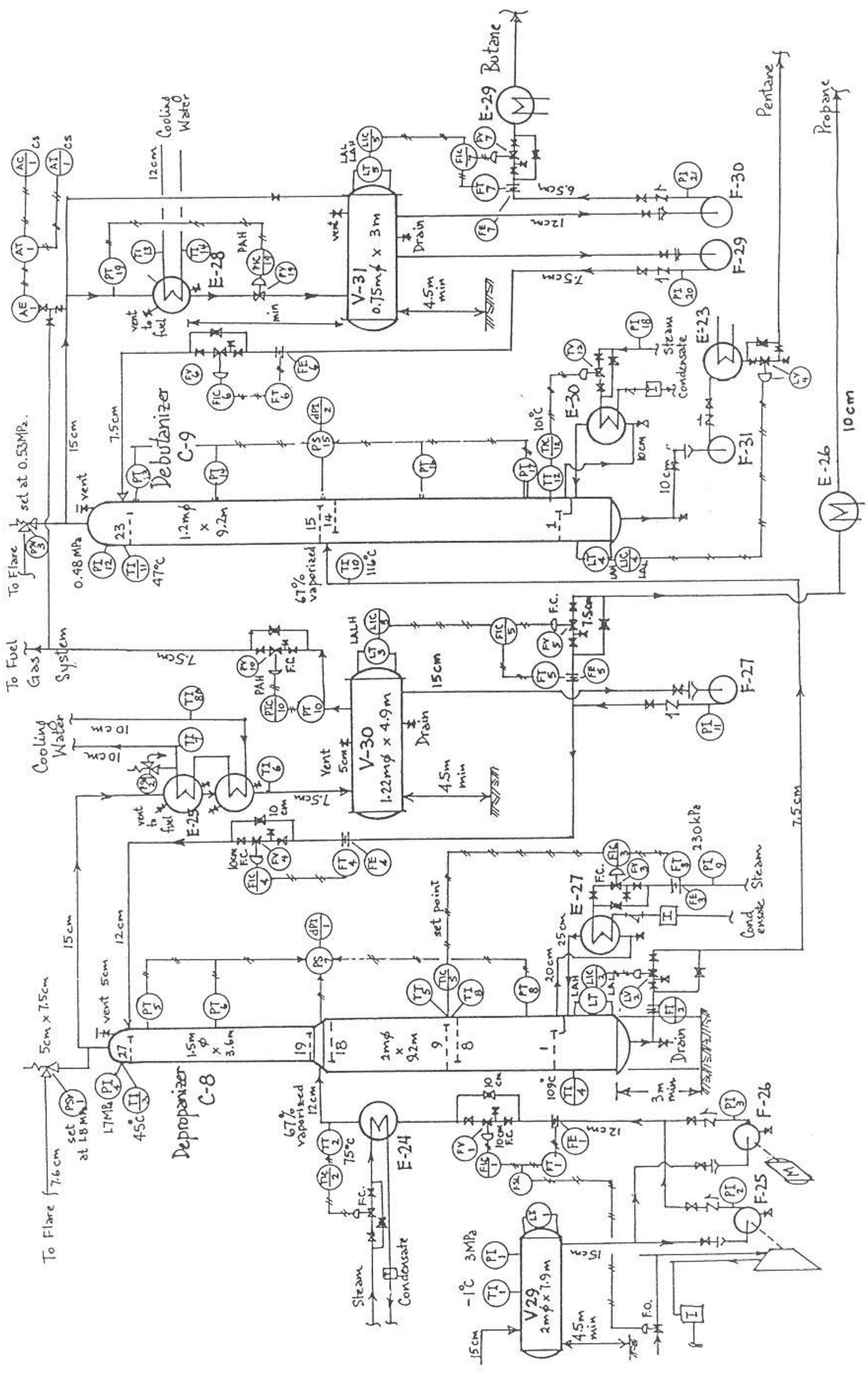
TROUBLE SHOOTING WORKSHOP

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.



PID-2A Depropanizer/Debutanizer

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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!

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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.

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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!

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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 <u>solution</u> as well as a problem to the plant manager. Time to apply your trouble shooting skills!