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What could have been occurring when you were enjoying your coffee?

- Primary coolant pumps stop
- Reactor control rods drop (SCRAM)
- Steam turbine stops
- Backup pumps start to circulate cooling
- Safety valve opens to relieve pressure
- Light indicates that safety valve closes
- Sufficient water in cooling loop, stop water makeup

Isolation valves around backup pumps are closed, violating policy!
No cooling water is circulated!

Since operators think water is OK, they shut off 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!

Operators think reactor is covered. Actually, reactor is not being cooled, is overheating!
What is needed to prevent such incidents?

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

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

**Three Mile Island Worksheet**

<table>
<thead>
<tr>
<th>Design deficiencies</th>
<th>Operations deficiencies</th>
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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

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 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

---

PROCESS TROUBLESHOOTING

**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

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**

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
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

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.
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
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!!
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

CLASS EXAMPLE
Should be:
Actually:
Initial state:
Final State:

Outlet Temp
Fuel flow rate
Feed rate

Let’s complete the definition.
PROCESS TROUBLESHOOTING

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

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

PROCESS TROUBLESHOOTING

CAUSE  Time  EFFECT

Feed flow  →  Heater outlet temperature

Feed temperature  ↓

Which direction would cause the effect?

??  ↓

What other causes influence the effect?

PROCESS TROUBLESHOOTING

- Check information and data!!!
  - Is the temperature actually decreasing?
  - Is fuel actually increasing?
  - What principles 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
2. Define
3. Explore
4. Plan
5. Implement
6. Evaluate

---

CLASS EXAMPLE

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

---

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?

---

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 issues.
## PROCESS TROUBLESHOOTING

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<th>DIAGNOSTIC ACTIONS</th>
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<td>Support, Disprove, Neutral</td>
<td>A B C D</td>
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<th>6. Evaluate</th>
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**Brainstorm causes**  
**Support/Neutral/disprove**

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

---

### 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

XXXX just could not happen.

• Do not be confrontational
• Based on principles
• Propose diagnostic action

• 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

INITIAL EVIDENCE (Support, Disprove, Neutral)

DIAGNOSTIC ACTIONS (Support, Disprove, Neutral)

WORKING HYPOTHESES

a b c d e A B C D

Brainstorm causes
Support/Neutral/disprove

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

They are based on the understanding developed during the “Explore” step, which is crucial for good trouble shooting.

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

**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 identify diagnostic actions to complete troubleshooting.

**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**

**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?
**Process Troubleshooting**

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

**Brainstorm causes**

**Support/Neutral/Disprove**

**Working hypotheses**

<table>
<thead>
<tr>
<th>Working hypotheses</th>
<th>Initial evidence (Support, Disprove, Neutral)</th>
<th>Diagnostic actions (Support, Disprove, Neutral)</th>
</tr>
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<tr>
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<td>b</td>
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<td>C</td>
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<tr>
<td>B</td>
<td></td>
<td>D</td>
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</table>

**Class Example**

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

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

### Brainstorm causes
- Support/Neutral/disprove

### INITIAL EVIDENCE

<table>
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<th>SUPPORT</th>
<th>DISPROVE</th>
<th>NEUTRAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
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</table>

### DIAGNOSTIC ACTIONS

<table>
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<th>DISPROVE</th>
<th>NEUTRAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
</tbody>
</table>

**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

---

**CLASS EXAMPLE**

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

*Let’s prepare the steps for achieving the desired state(s).*
PROCESS TROUBLESHOOTING

Achieve the first desired state rapidly!

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

Achieve the final desired state.

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

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

**Successful Troubleshooting Lesson**

**Unsuccessful TS Practice**

**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! .....](image1)

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.](image2)

4. Accept all information as relevant and correct.
Slide 73

**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.

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

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

• When it matters, we have to produce immediately.

Slide 74

**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?

Slide 75

**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.


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


Additional references:

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

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.
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!