# Master in Control Engineering

# Process Automation
# 2020-2021

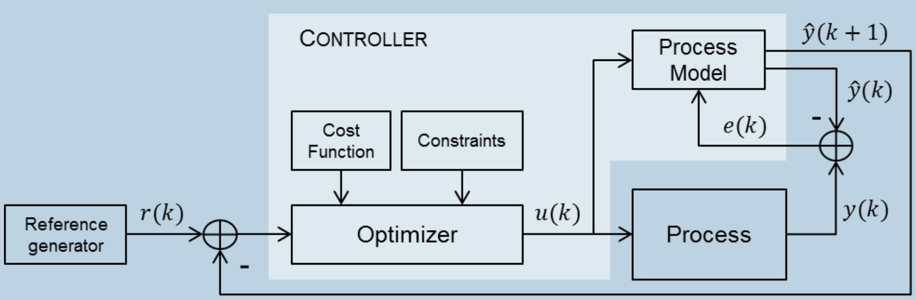
Dipartimento di Ingegneria informatica automatica e gestionale Antonio Ruberti

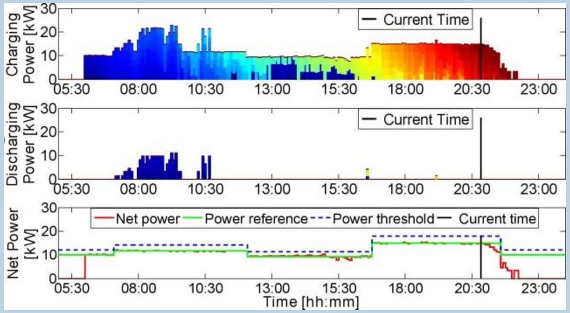
Sapienza
Università di Roma

Master in Control Engineering

# Process Automation

## 1. Course Overview



# Summary

- Course overview
  - Practical information
  - Significance of process control
  - Course focus and organization

# Practical information

- Contacts
  - Antonio Pietrabissa (PhD)

    Associate Professor

    Dept. of Computer, Control and Management Engineering “Antonio Ruberti” (DIAG)
    Università di Roma "La Sapienza

    Via Ariosto 25, 00185, Roma

    Room A213
    tel.: +39 06 77274040
    email: pietrabissa@diag.uniroma1.it
  - Office hour

    Thursdays, 12:15-13:15
    Google Meet: https://meet.google.com/ifz-wpjj-bfm
    (please write me an email for any circumstances)
  - Research group

    Networked Systems (http://www.diag.uniroma1.it/gruppi-di-ricerca/18328)

    EU-funded ongoing research projects:
    5G-ALLSTAR (https://5g-allstar.eu/)
    5G-Solutions (https://www.5gsolutionsproject.eu/)
    SESAME (https://eurecat.org/en/portfolio-items/sesame/)

# Practical information

## PROCESS AUTOMATION

- I year of Master of Science in Control Engineering (MCOR)
- Number of ECTS credits: 6 (48-60 hours)
- Course web page: https://sites.google.com/a/diag.uniroma1.it/antonio-pietrabissa/home-page-en/teaching/process-automation

- Course schedule

Office hour (Google Meet)
Thursdays, h12:15-13:15

| | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MON | | | | | | | A7 | A7 | | | |
| TUE | | | | | | | | | | | |
| WED | | | | | | | | | | | |
| THU | | A4 | A4 | A4 | Office Hour | | | | | | |
| FRY | | | | | | | | | | | |

# Practical information

PROCESS AUTOMATION

- Reference texts
  - *Slides and notes available via the website*
  - Dale E. Seborg, Thomas F. Edgar, Duncan A. Mellichamp, "Process Dynamics and Control", Wiley, 2nd ed., 2003, 736 p., ISBN 978-0471000778.
  - Rivera, Daniel E. "Internal model control: a comprehensive view." Arizona State University (1999).
  - Eduardo F. Camacho, Carlos Bordons Alba, “Model Predictive Control”, Series: Advanced Textbooks in Control and Signal Processing, XXII, 2nd ed. 2004, 405 p., ISBN 978-0-85729-398-5.

- Process Automation group
  - "Process Automation 2020/2021" group on Microsoft Teams (subscribe with a "...uniroma1.it" email address; if you don't have the university address yet, please contact me).
  - <u>Subscription required to download the course slides and notes</u>

# Practical information

PROCESS AUTOMATION

- **Exams**

  I and II session: January 7 – February 19

  Extra session: March 15 – April 21 (for students enrolled on supplementary years of studies)

  III and IV session: May 31 - July 23

  V session: September 1 - September 17

  Extra session: October 4 – November 5 (for students enrolled on supplementary years of studies)

  – Usually, written exam with 2 problems and 2 questions, oral discussion afterwards

# Course Outline

- Part I – Process automation overview
  - Definition of dynamic system models for process control
  - Define basic process models (input-output, transfer function, time-delay systems)

- Part II – IMC and Smith Predictor
  - Classical process control methods
    - Robust PID control and Internal Model Control (IMC)
    - Time-delay systems and robust Smith Predictor (SP) controllers

- Part III - MPC
  - Concepts and methodologies related to Model Predictive Control (MPC)
  - Basic MPC algorithms
    - Dynamic Matrix Control (DMC)
    - Model Algorithmic Control (MAC)
    - Predictive Functional Control (PFC)
  - MPC, optimal control and stability

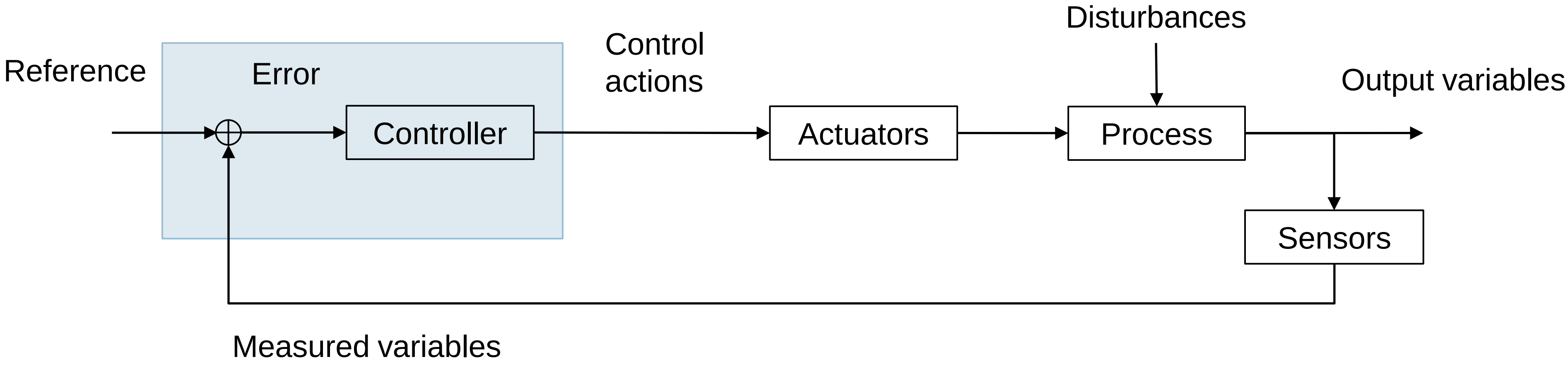
# Significance of process control

- Industrial processes are controlled in order to
  - minimize cost while maximizing production
  - maximize safety
  - limit effects on the environment

- Automation
  - Process controls
    - Given a change in system response, the control system automatically counteracts
    - Example
      - Before automation
        - » A technician is needed to monitor the temperature in a reaction vessel, and operates a valve to manipulate the cooling water flow rate in the jacket
      - With automation
        - » The control system algorithm, fed by the temperature measure, calculates the control command to operate the valve to manipulate the cooling water flow rate

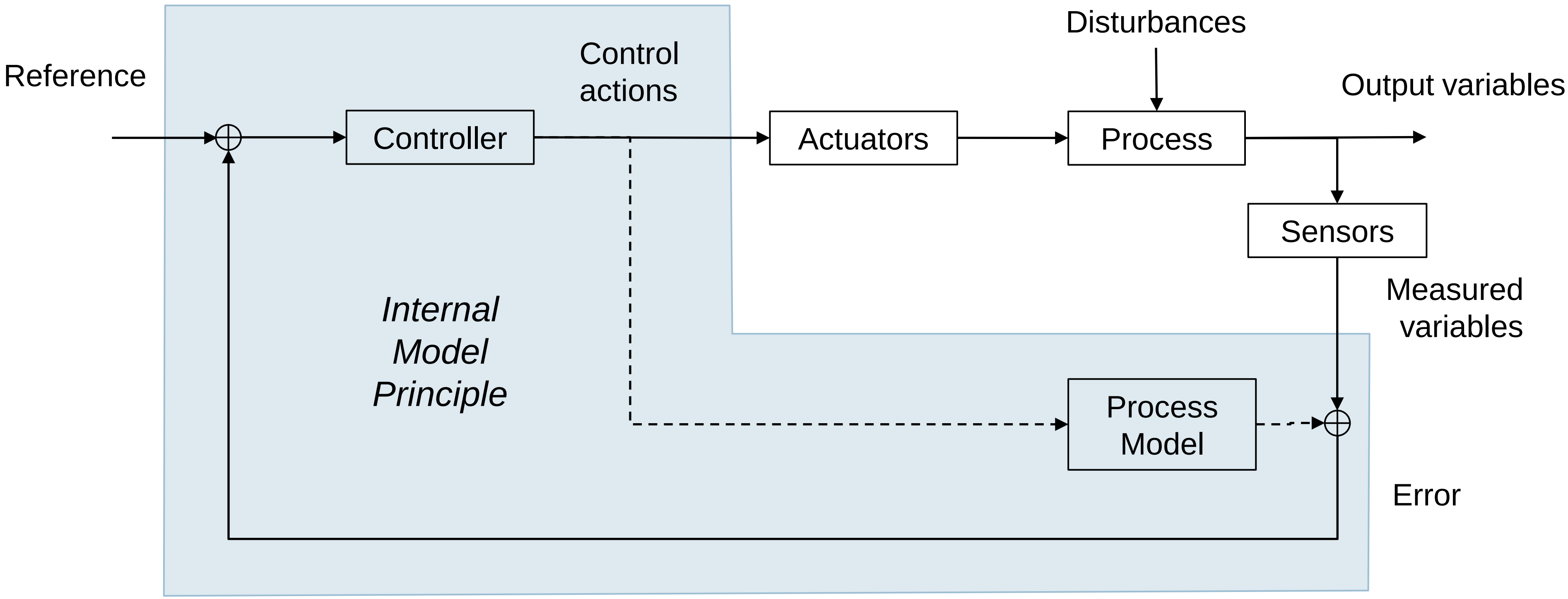
# Process control

- Automation
  - By designing an effective control system, even the most complicated of processes can be run with <u>minimal worker supervision</u>
    - Decreasing of **operating cost**
    - Increasing of **performance**
    - Increasing of **safety**
  - From classic feedback control scheme…



# Process control

- Automation
  - …to *model-based design*…



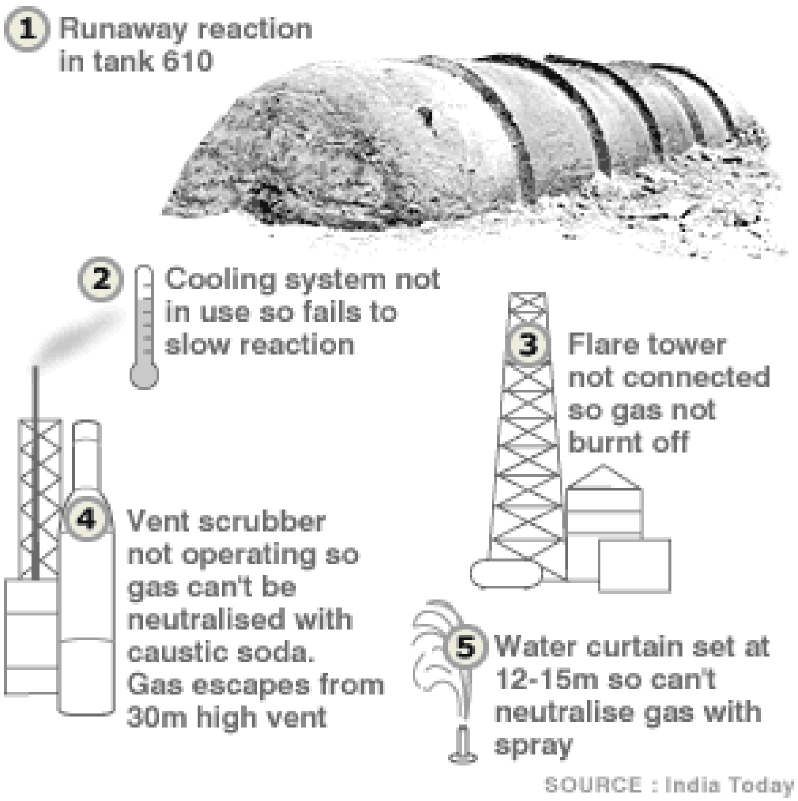
# Process Control

- Requisites for the development of a control system
  - 1. Understand the process
    - Control objectives
    - Identify
      - Disturbances
      - Control variables
      - Output variables
      - State variables
      - Relations among variables
    - Define a *dynamic model* and understand its limitations
  - 2. Process Instrumentation
    - Sensor and actuator selection and integration
    - Communication network selection and integration
    - Computer architecture
  - 3. Process Control
    - Design an appropriate control strategy to achieve the control objectives

# Failures in process control

https://controls.engin.umich.edu/wiki/index.php/Failures_in_Process_Control

- Bhopal gas tragedy, India, December 3, 1984
  - A large toxic gas leak that killed thousands of people in the surrounding area
    - A tank with 42 tons of *methyl isocyanate* (MIC) was contaminated with water
    - This in turn caused a runaway reaction that greatly increased the pressure and temperatures in the tank
    - Pressure and temperature increase forced the <u>emergency venting of the toxic gases to the atmosphere</u>



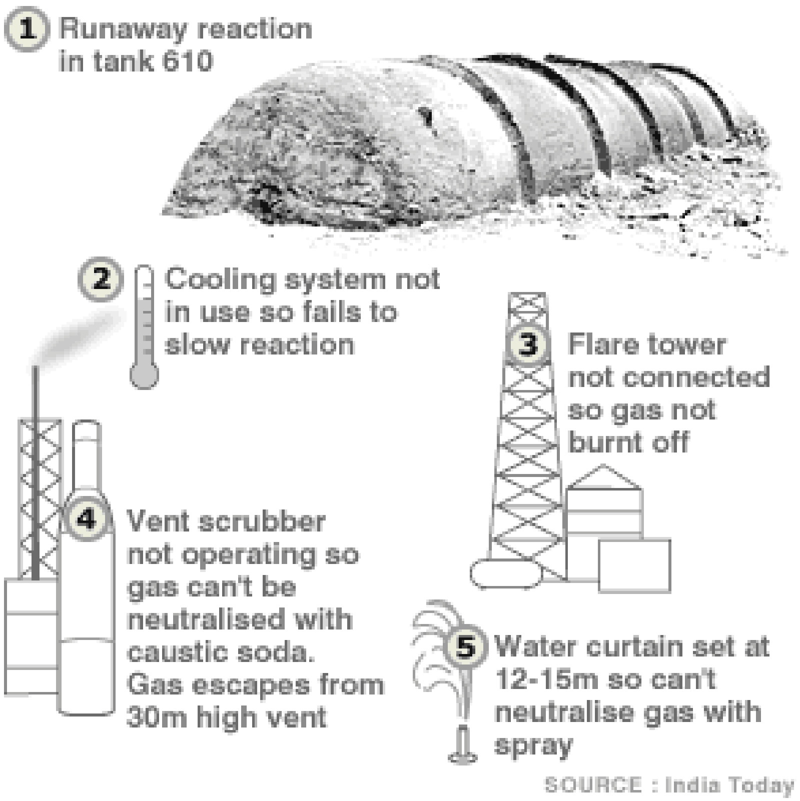
# Failures in process control

https://controls.engin.umich.edu/wiki/index.php/Failures_in_Process_Control

- Bhopal gas tragedy, India, December 3, 1984

This tragedy was largely due to the failure or lack of safety controls

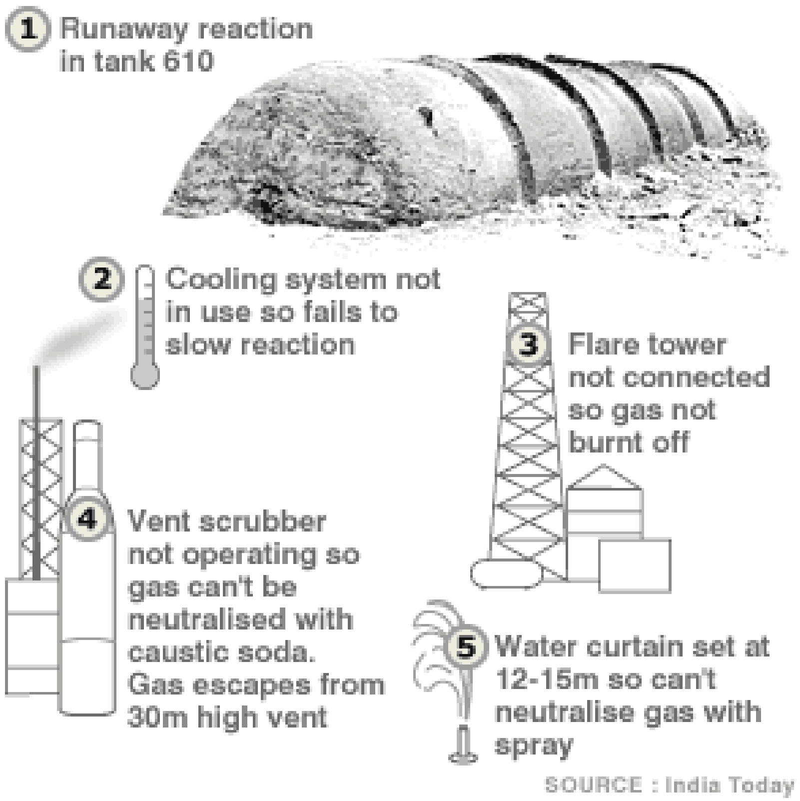
1. Unregulated runaway reaction as temperature and pressure increased
2. MIC was supposed to be cooled, but, in the Bhopal plant, the refrigeration system was not turned on
    - » Temperature control on the tank could have avoided the runaway reaction
3. Flare tower to handle the leakage of toxic gases was not functional



# Failures in process control

https://controls.engin.umich.edu/wiki/index.php/Failures_in_Process_Control

- Bhopal gas tragedy, India, December 3, 1984
  4. The vent scrubber was not operating, so gas couldn't be neutralized with caustic soda
  5. Water curtain, which would neutralize some escaping gas, were not designed properly
     - » It was not tall enough to reach the top of the flare tower, making it worthless
  6. Alarms that would have alerted to a malfunction in the tank had not been operational for 4 years



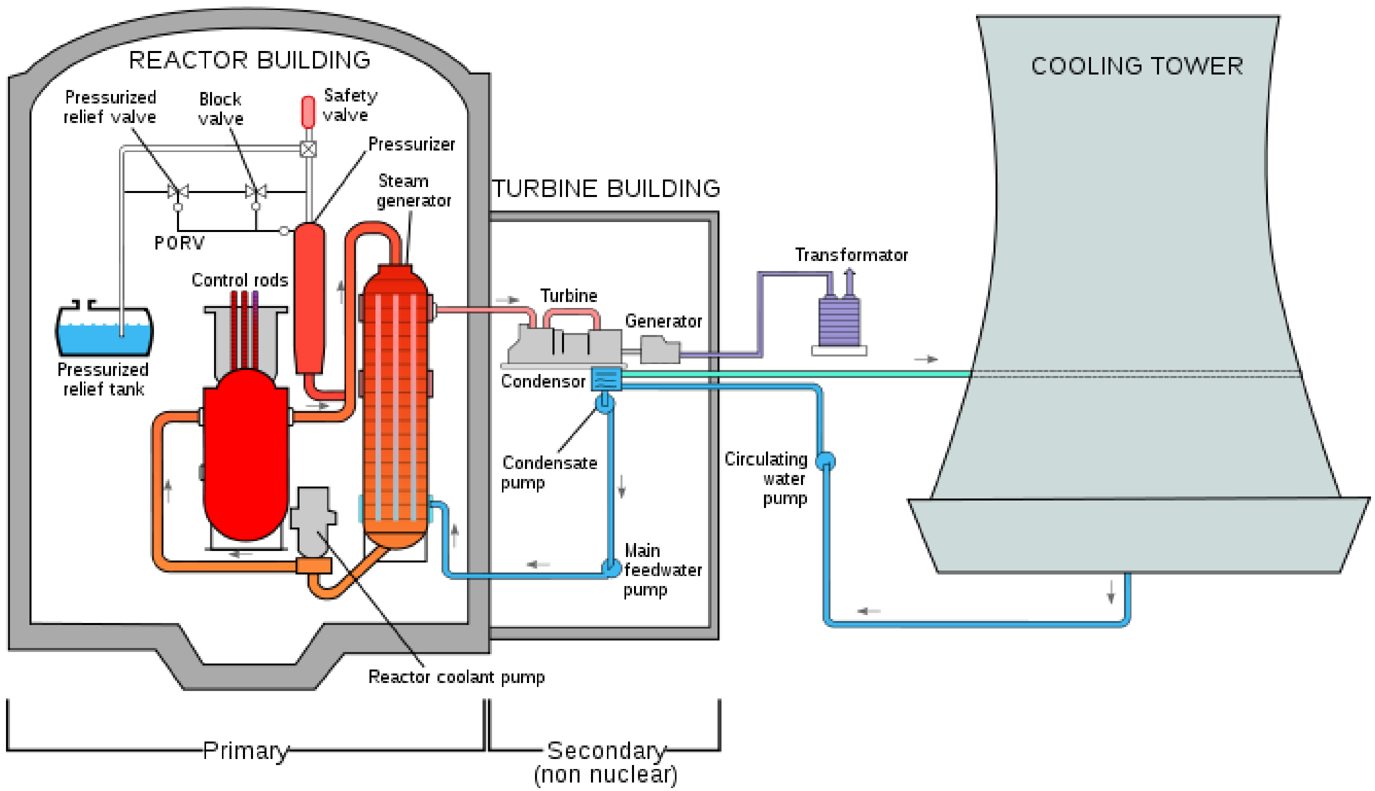

Had at least some of these been functioning the amount of toxic gas released, and of casualties, would have been substantially reduced

Dominique Lapierre, Javier Moro, «Five Past Midnight in Bhopal», 2001

# Failures in process control

https://controls.engin.umich.edu/wiki/index.php/Failures_in_Process_Control

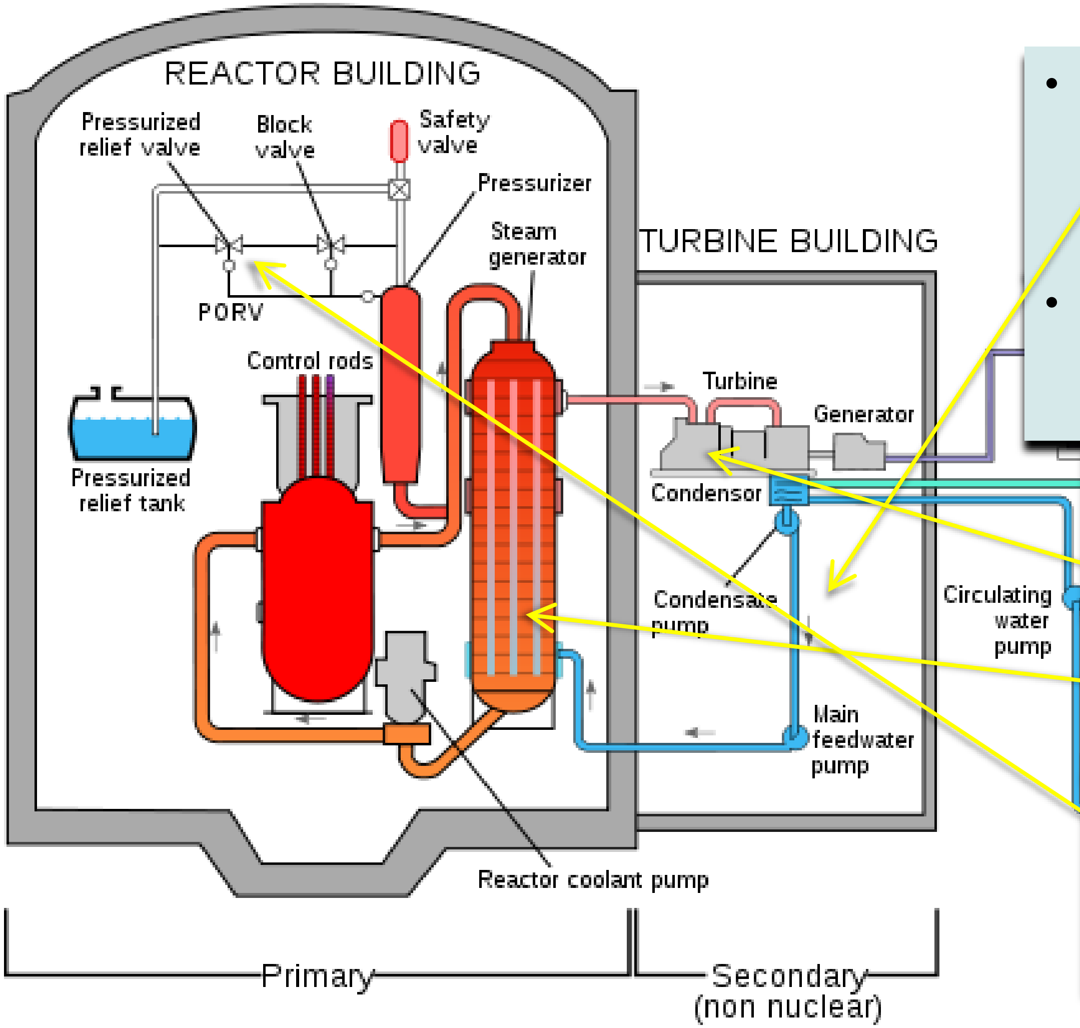
- Three Mile Island Disaster, USA, March 1979
  - Nuclear power plant on the Three Mile Island
  - The nuclear fuel melted (as happened at Chernobyl) but, luckily, the accident was largely contained



# Failures in process control

https://controls.engin.umich.edu/wiki/index.php/Failures_in_Process_Control

- Three Mile Island Disaster, USA, March 1979

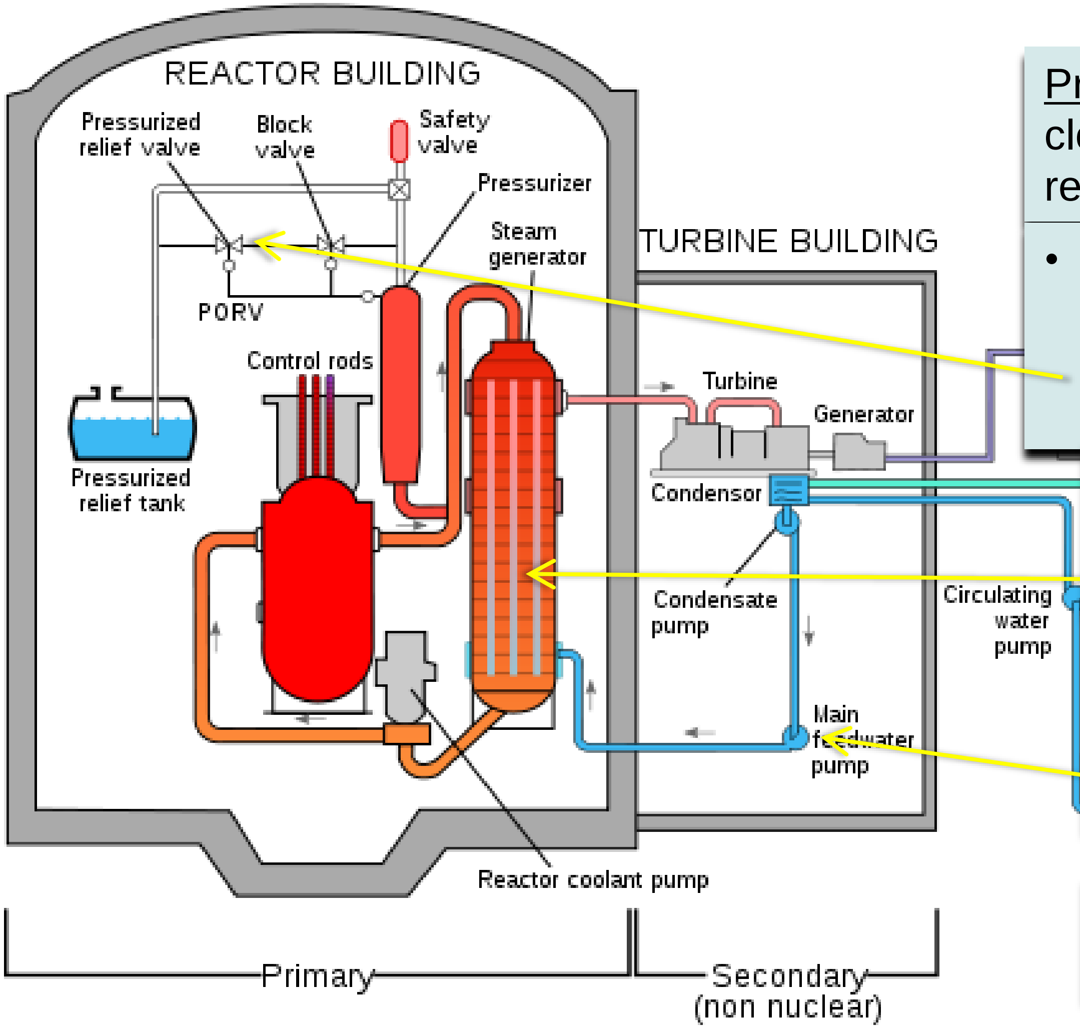



- Either a mechanical or electrical failure of the main feed water pumps causing the power plant to begin to overheat
- Control actions were properly designed to prevent a significant event from happening
  - As the heat increased, the control scheme caused the *turbine and reactor* to shut down
  - This caused a *pressure increase* in the primary system (nuclear portion of the plant)
  - *A relief valve* automatically opened to release some of the pressure to prevent the reactor from blowing

# Failures in process control

https://controls.engin.umich.edu/wiki/index.php/Failures_in_Process_Control

- Three Mile Island Disaster, USA, March 1979




Problem: the release valve did not close properly when the pressure in the reactor was relieved

- When the reactor started back up, coolant in the core of the reactor was lost through the pressure relief valve
  - There was no control mechanism that measured the level of the coolant in the reactor
  - The operators, who only judged the water level by the pressure in the reactor, actually decreased coolant flow to the reactor

Control design failure prevented the operators from cooling the reactor

# Failures in process control

- Černobyl’ disaster (1986)
  - Chernobyl (HBO ©) scene
    Valery Legasov explains, how an RBMK reactor works

# Course organization

- This course won't focus neither on current process automation technology
  - e.g., PLC, valves, SCADA, …

  nor on specific process model
  - e.g., chemical processes, distillation processes, …

  but on process control models and control methodologies
  - PID control
  - Internal Model Control (IMC)
  - Model Predictive Control (MPC)

- Why?

  - «Nowadays, *most part of the <u>notions</u> learned at the university will be irrilevant when the student will be graduated*» (CEO of a big consultancy firm)

  - «*<u>Ideas</u> are much harder to explain with respect to apparatuses*» (A. Isidori)

# Course organization

- Classic process control
  - Robust control of SISO linear systems
    - Frequency domain robust stability theorem
  - Robust Internal Model Control (IMC)
    - Useful for typical process model and for PID tuning
  - Smith Predictor (SP) controller
    - Compensation technique for time-delay system

# Course organization

- MPC
  - MPC is deemed as  the most general way of posing the process control problem in the time domain
    - MPC gracefully handles constraints and nonlinear processes – which are frequently found in industry – thanks to the *finite control horizon* strategy
  - MPC has developed considerably over the last decades
    - Within the industry due to large success in real applications
    - Within the research control community due to theoretical results on robustness and stability
  - Model Predictive Control formulation integrates
    - Optimal control
    - Stochastic control
    - Control of processes with dead time
    - Multivariable control
    - Robust control

# Course organization

*Prerequisites*

Basics on Systems Theory

Basics on Feedback Control

Basics on Optimal Control and Operations Research

## PROCESS AUTOMATION

### Part I: Process Automation Overview

Brief overview on
- dynamic system models for process control
    - application examples
- model identification
- process safety

*Theory*

### Part II: Classical Process Control

Robust Control for LTI systems

Internal Model Control

Smith Predictor

*Theory + exercises*

### Part III: Model Predictive Control

Model Predictive Control principles

Industrial MPC Algorithms

MPC, optimal control, stability

Dynamic Matrix Control

Model Algorithmic Control

Predictive Functional Control

*Theory + exercises*