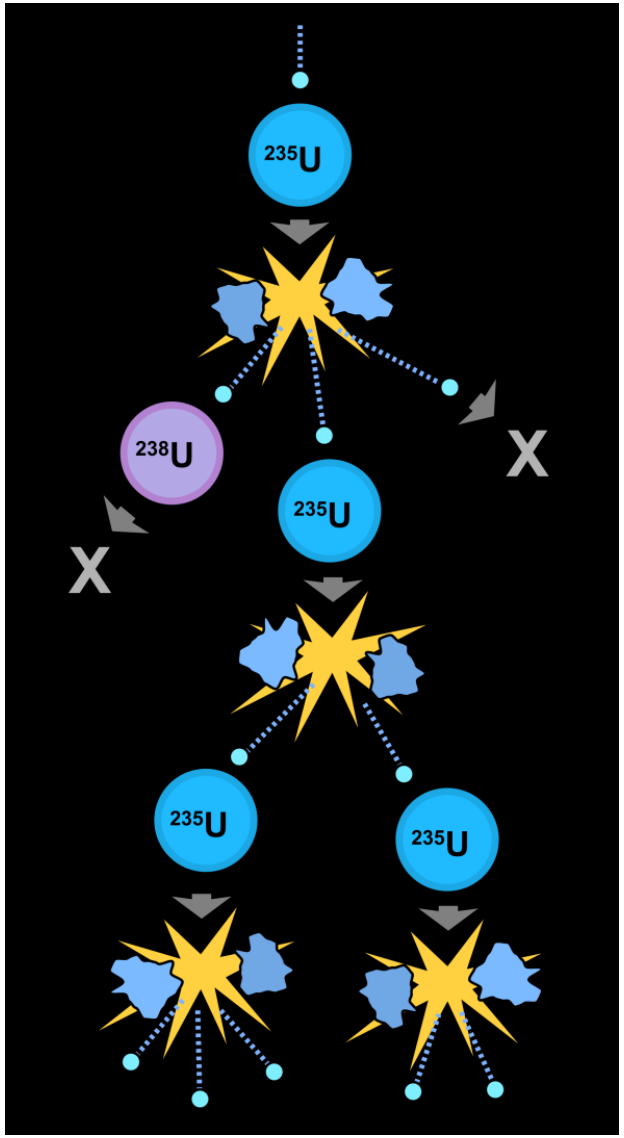
INL/MIS-25-85355

Katya Le Blanc

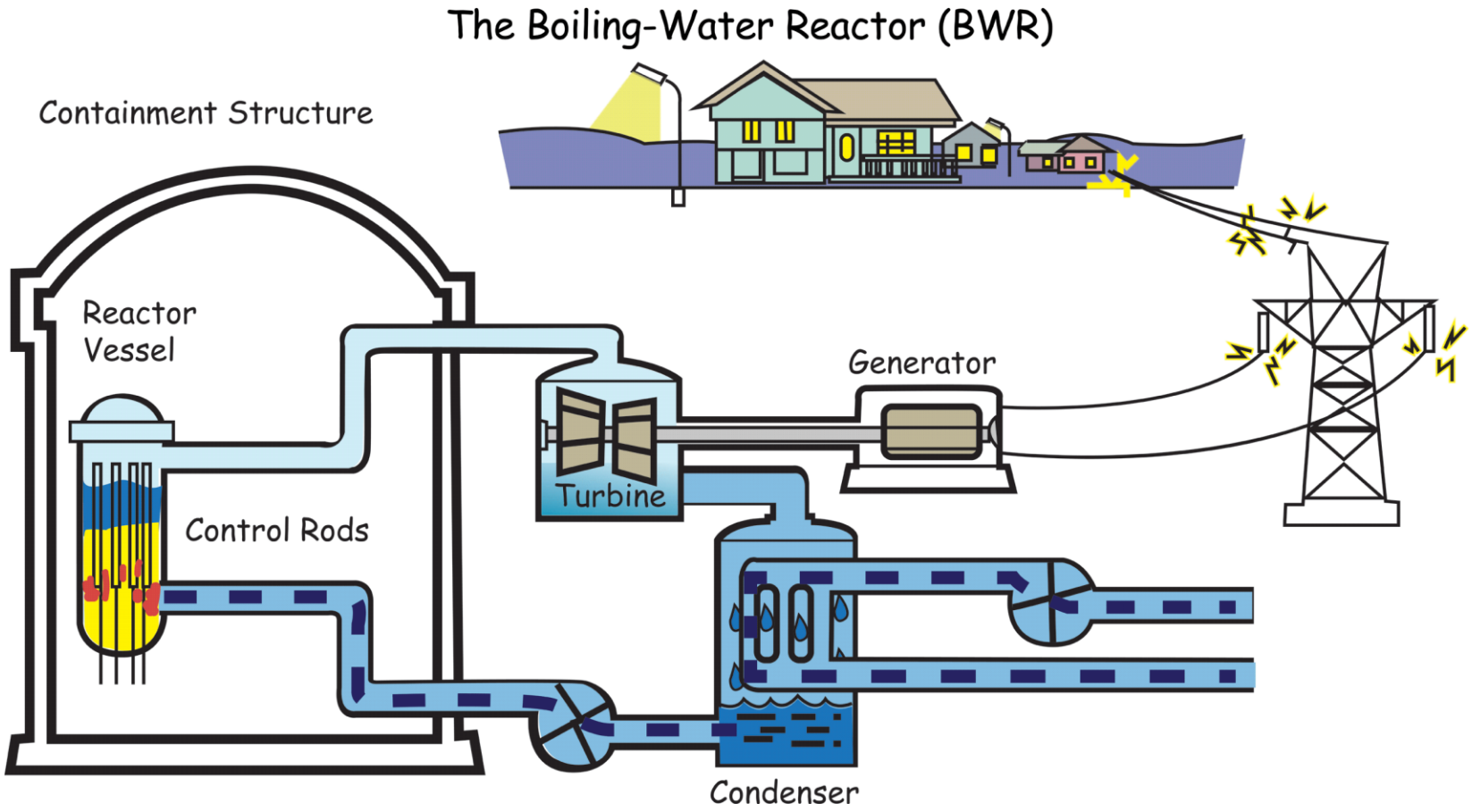
Nuclear Power Fundamentals

Idaho National Laboratory

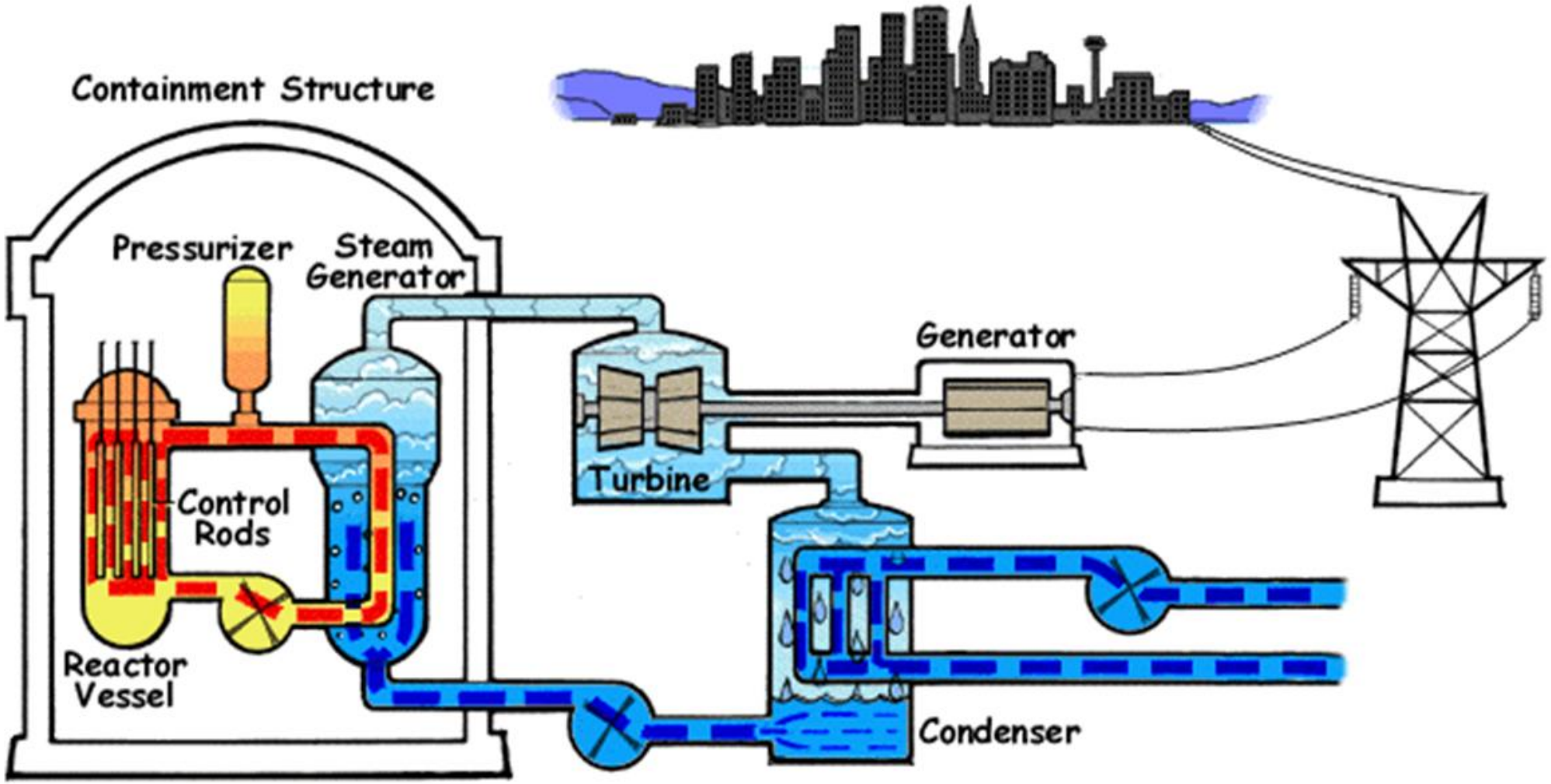
Fission



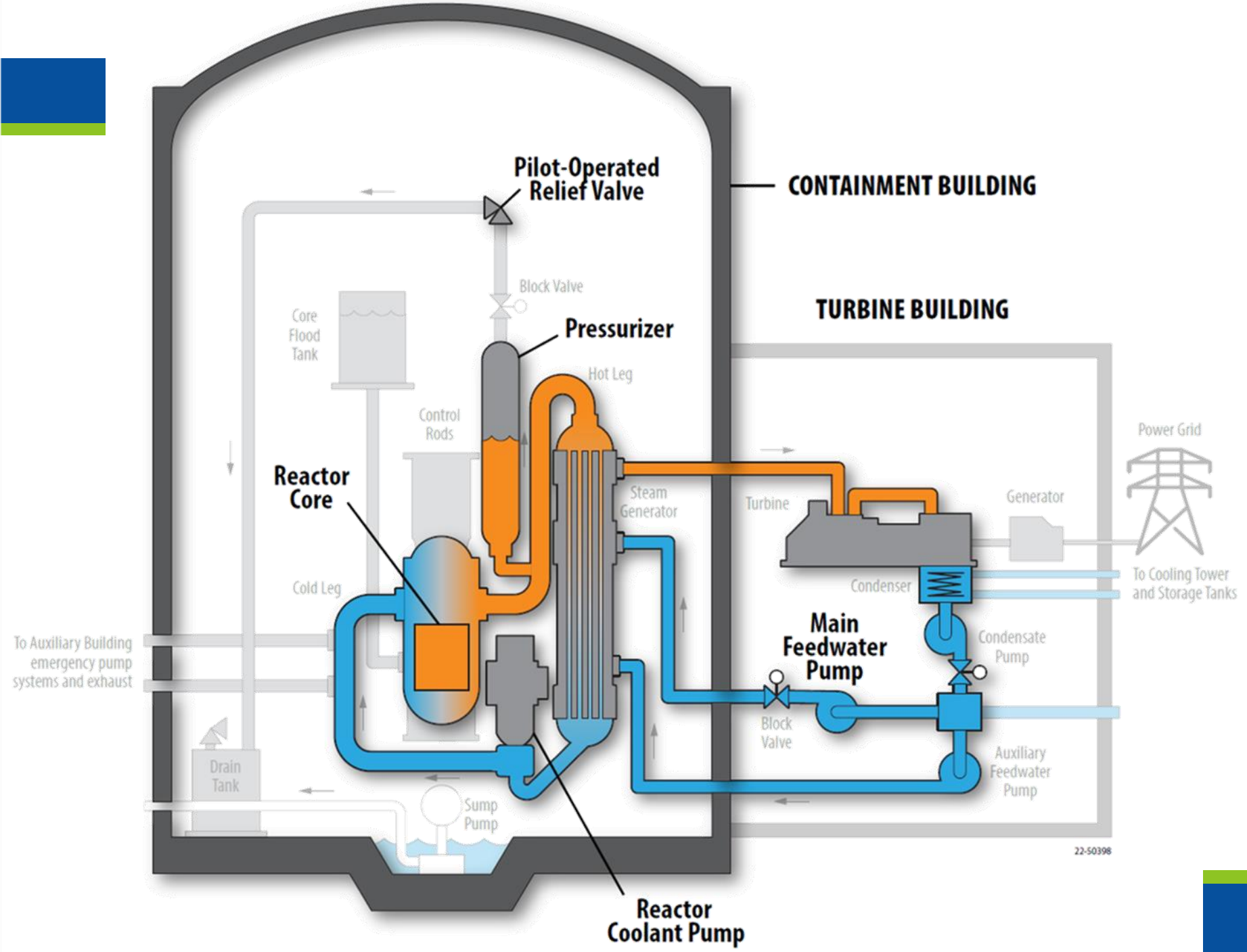
Boiling Water Reactor (BWR)



Pressurized Water Reactor (PWR)



Some History:Three Mile Island

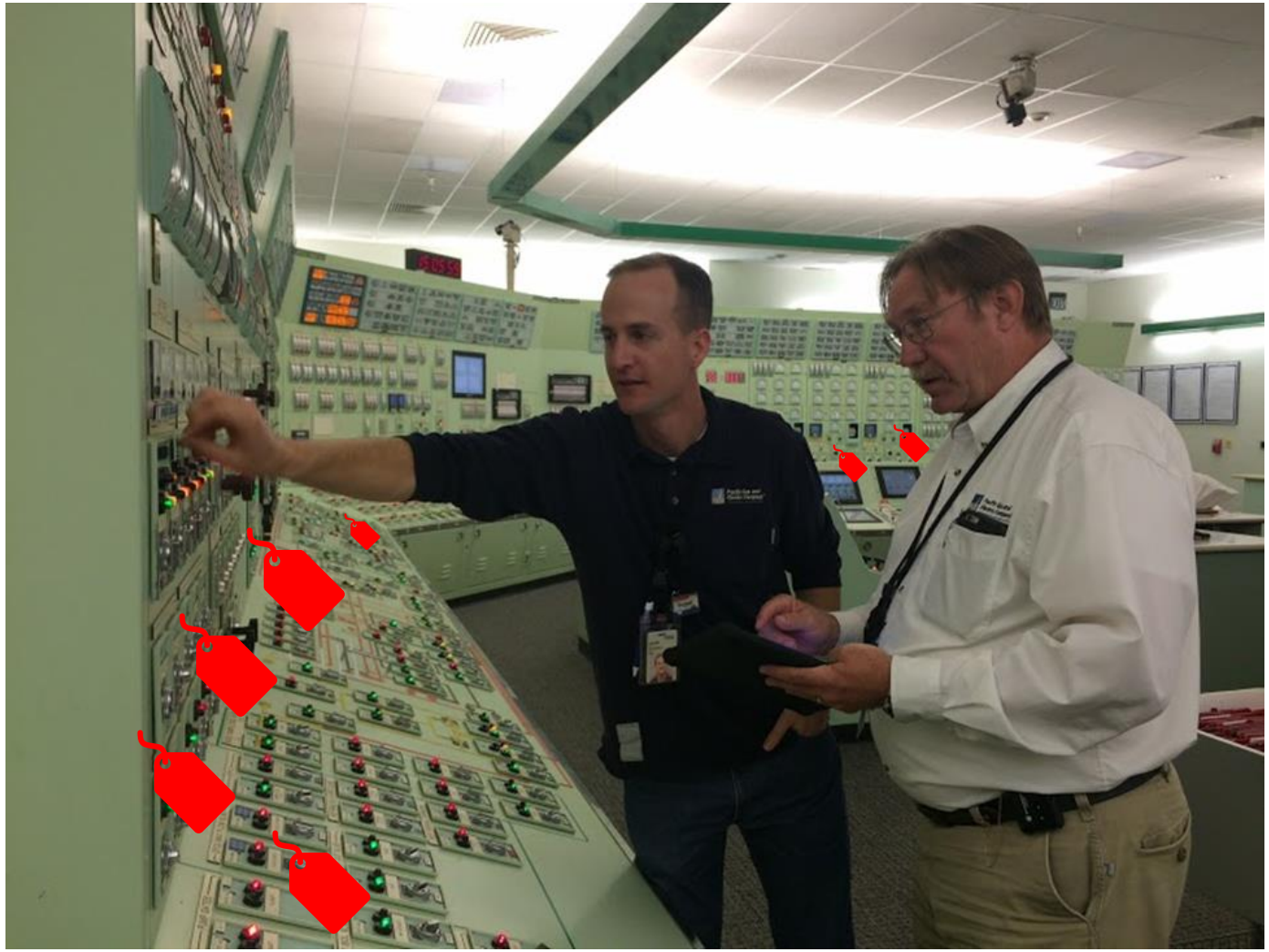

Pilot-Operated Relief Valve
CONTAINMENT BUILDING
Block Valve
TURBINE BUILDING
Core Flood Tank
Pressurizer
Hot Leg
Control Rods
Power Grid
Reactor Core
Steam Generator
Turbine
Generator
Cold Leg
Condenser
To Cooling Tower and Storage Tanks
To Auxiliary Building emergency pump systems and exhaust
Main Feedwater Pump
Condensate Pump
Block Valve
Drain Tank
Auxiliary Feedwater Pump
Sump Pump
22-50398
Reactor Coolant Pump

Setting the stage

Diablo Canyon Control Room

- Control rooms are a complex and noisy environment
- It is 4 am
- In an event, 100s of alarms are going off

Setting the stage

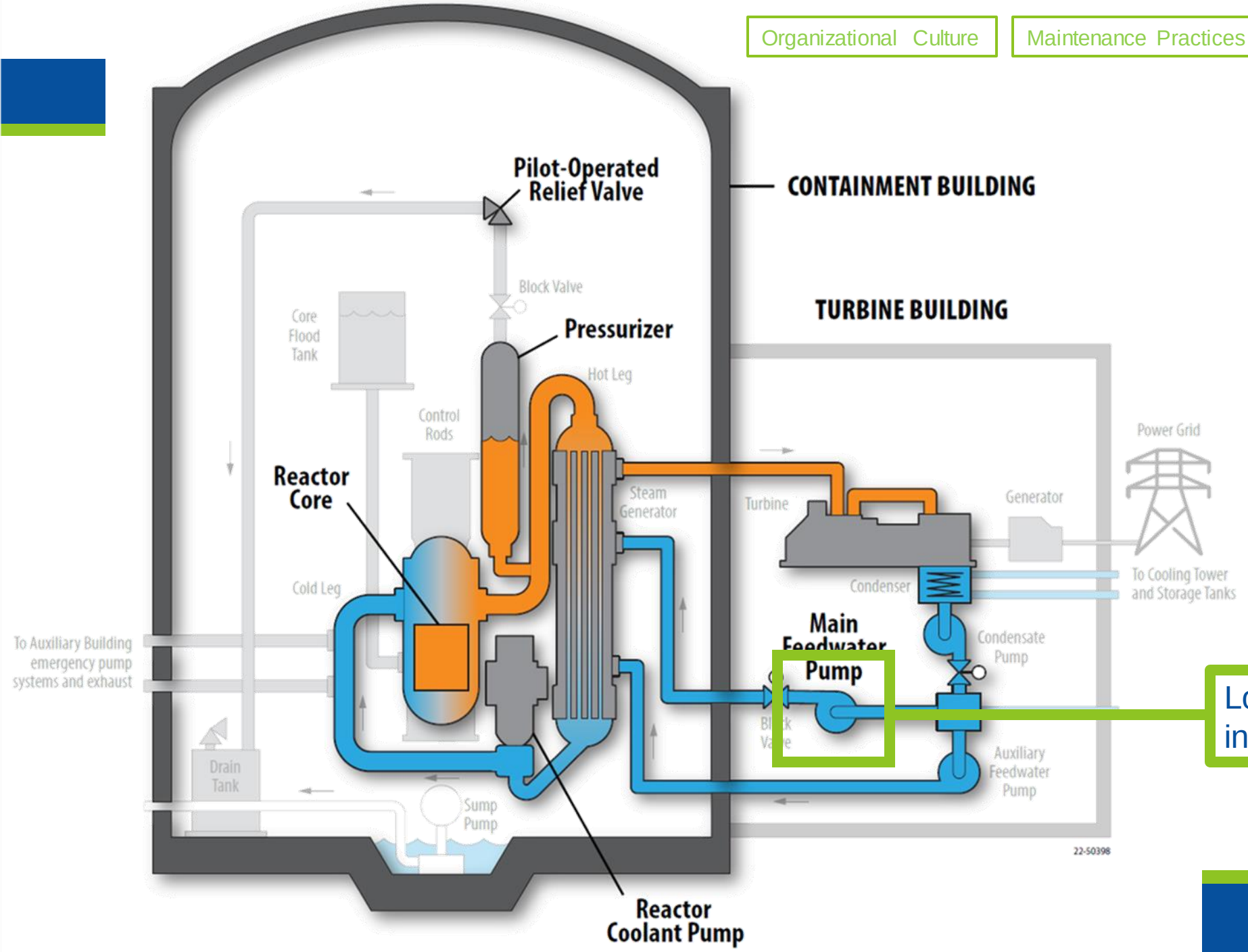


Diablo Canyon Control Room

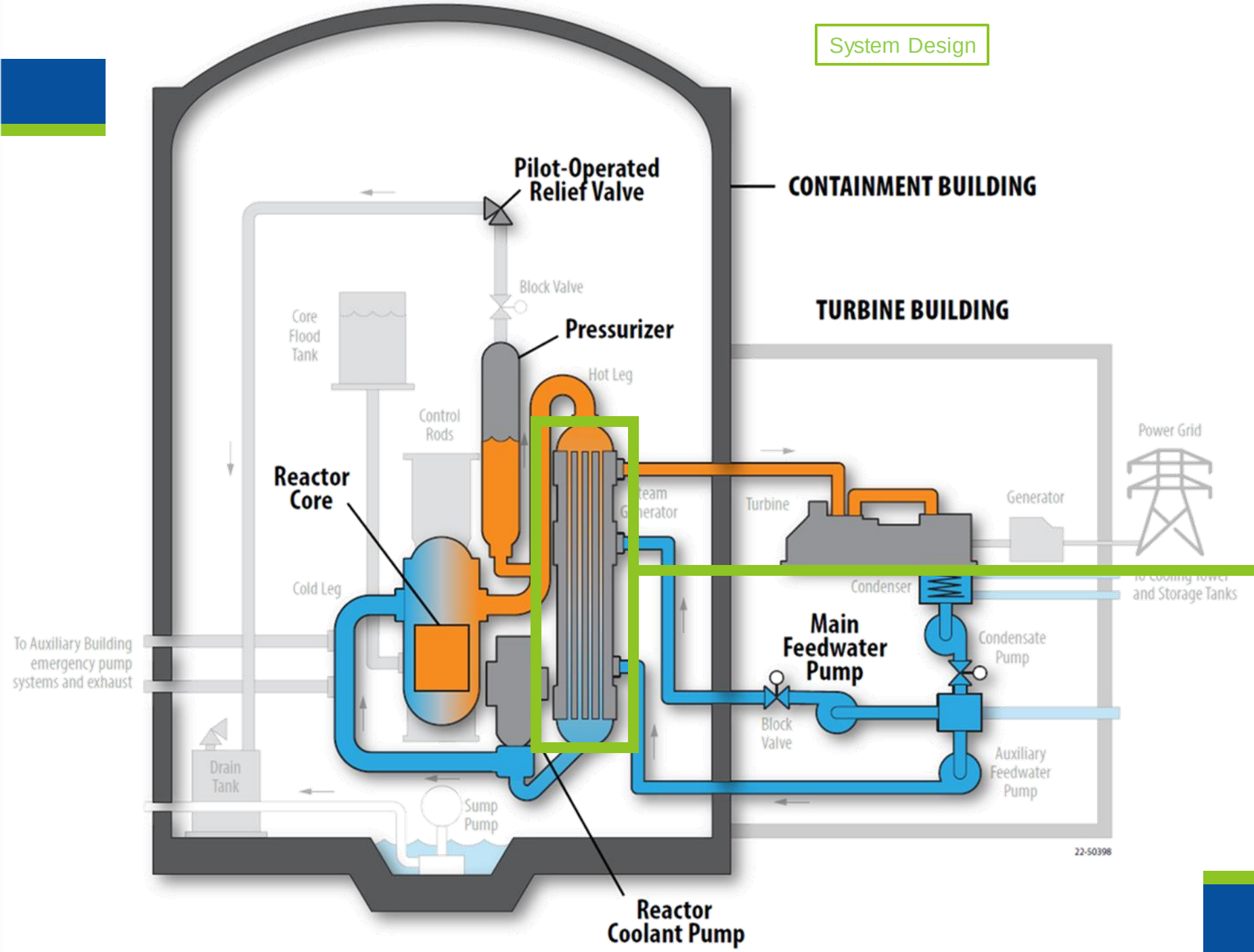
- Control rooms are a complex and noisy environment
- It is 4 am
- In an event, 100s of alarms are going off
- There were many systems out of service the day of the event

Organizational Culture

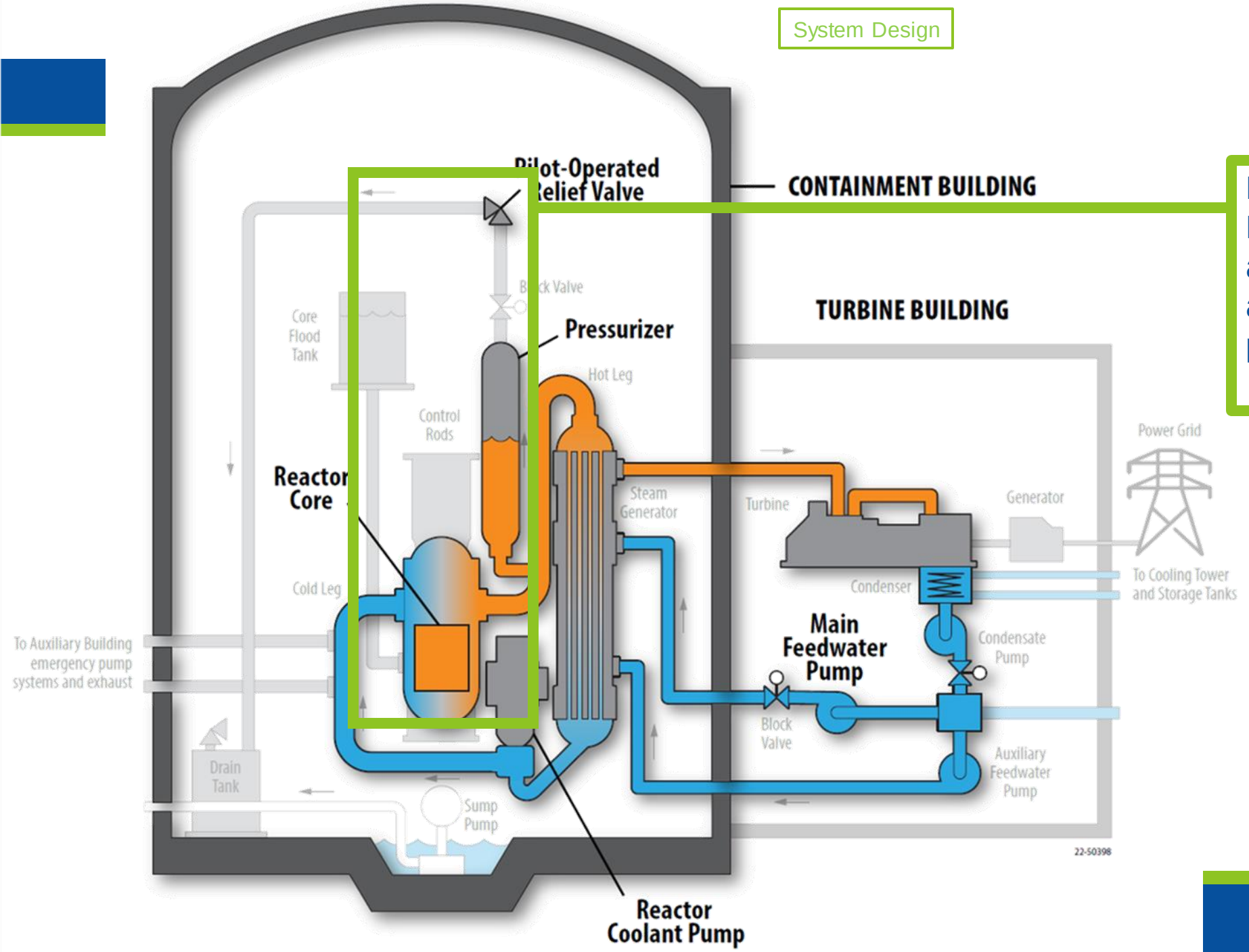
Maintenance Practices



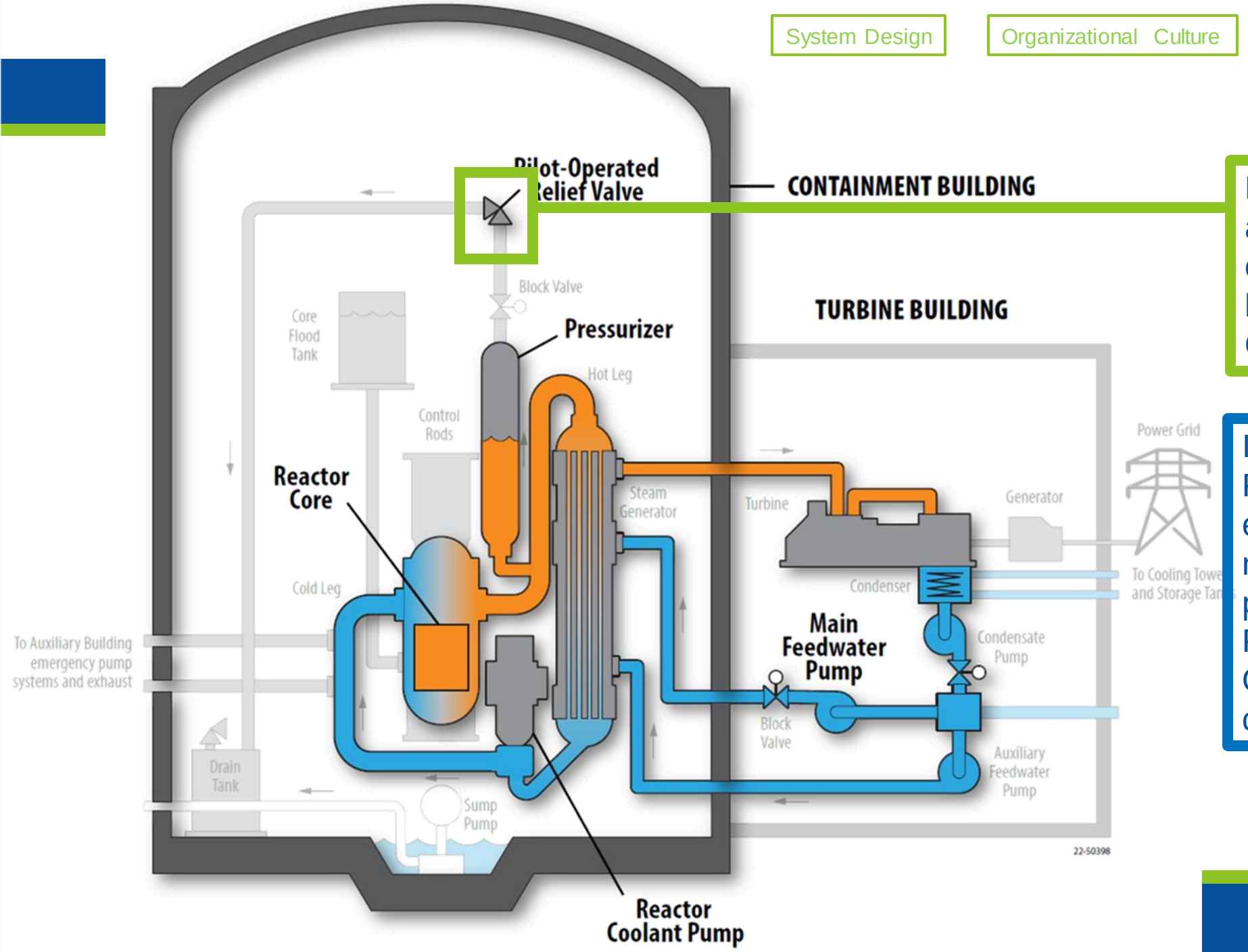
Loss of Main Feedwater initiated the event



Steam Generator boils dry <2 Minutes

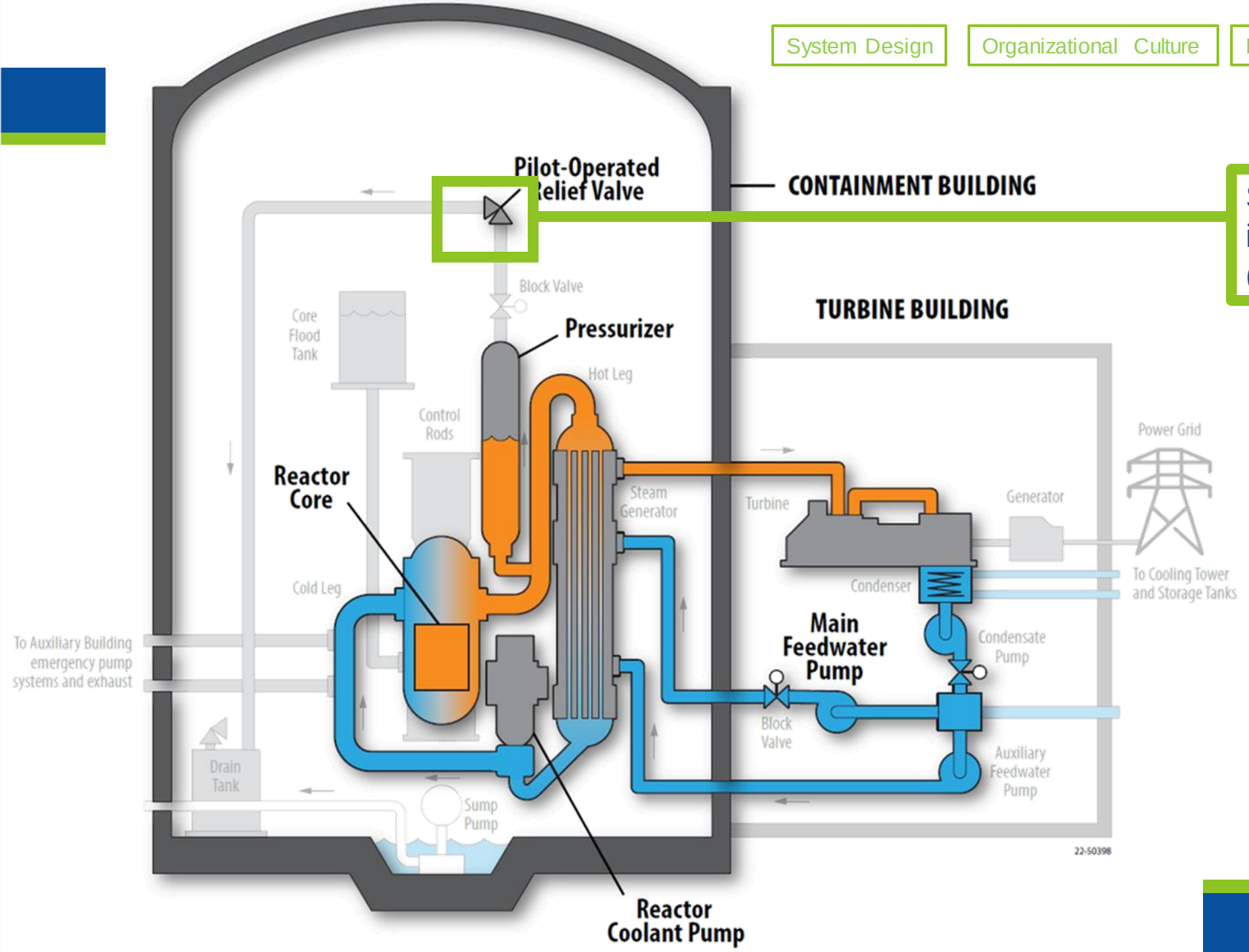


Primary System Pressure Increases, and PORV opens automatically to relieve pressure



Pressure is relieved, and automatic signal to close PORV is sent, however PORV is stuck OPEN

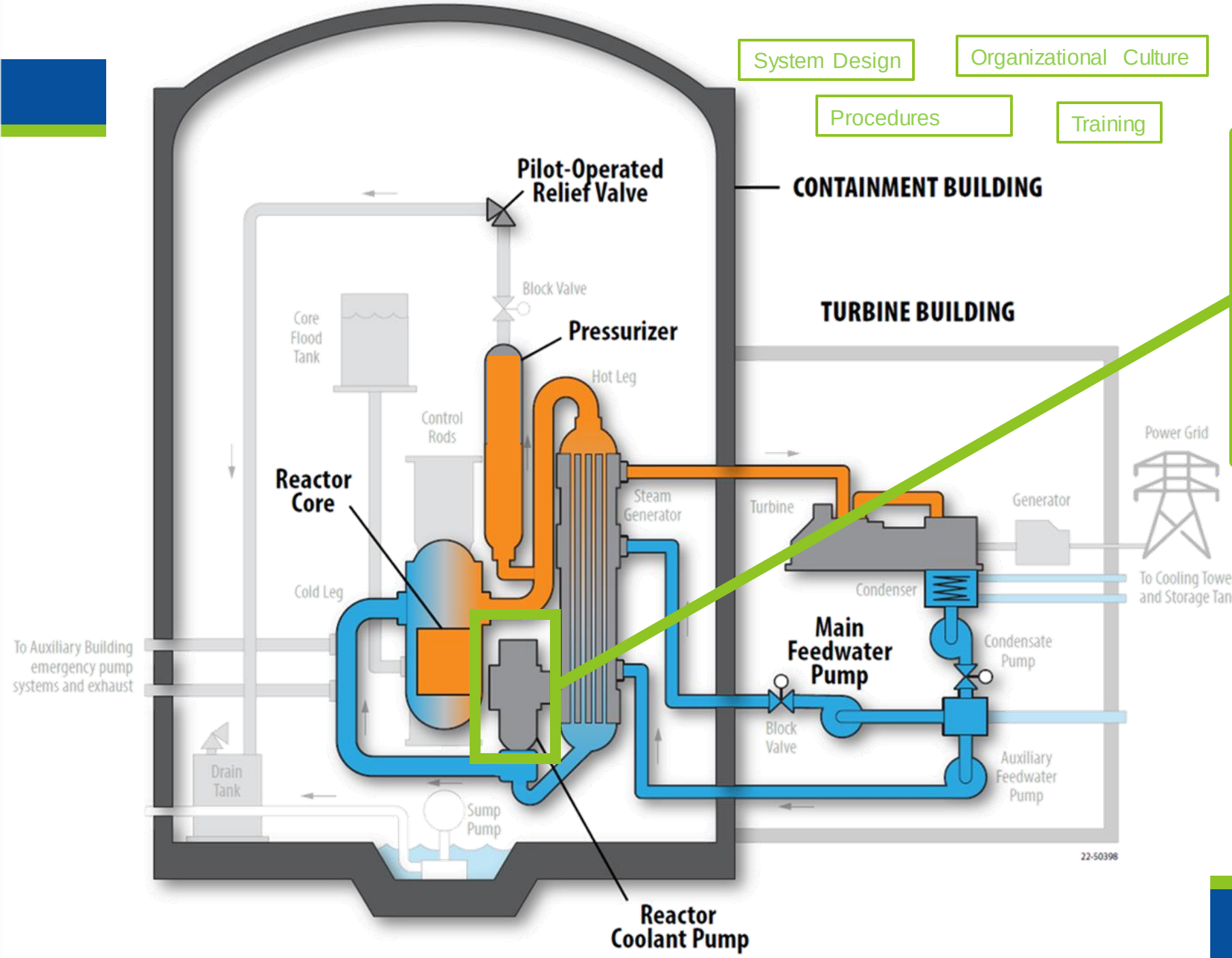
Indicator on Control Panel relies on electrical signal, and not actual valve position, so it indicates PORV is CLOSED, Operators believe it is closed



Stuck Open PORV initiates Loss of Coolant (LOCA)

System Design | Organizational Culture | Experience and Expectations

Procedures | Training

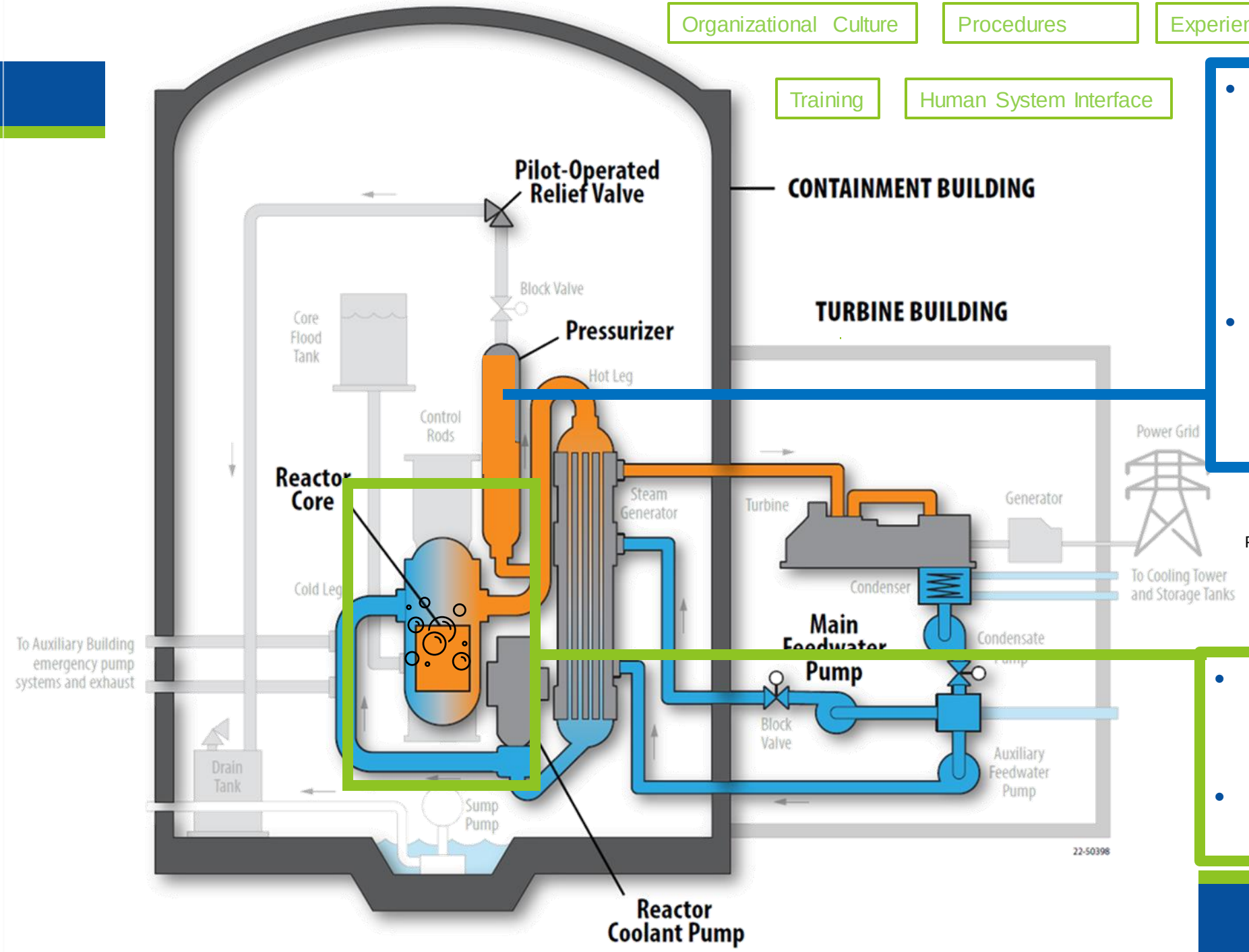


- Level in Primary System increases
- Pressure is dropping
- High Pressure Injection (HPI) is automatically initiated (would normally indicate LOCA)

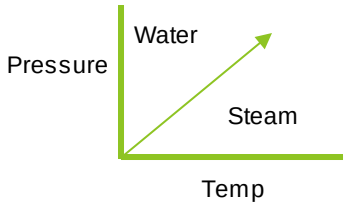
- Operators have previously seen HPI actuation in non-LOCA conditions

Organizational Culture | Procedures | Experience and Expectations

Training | Human System Interface



- Operators are **trained** to use pressurizer level indications for primary coolant inventory
- Do not recognize that the system has reached saturation conditions



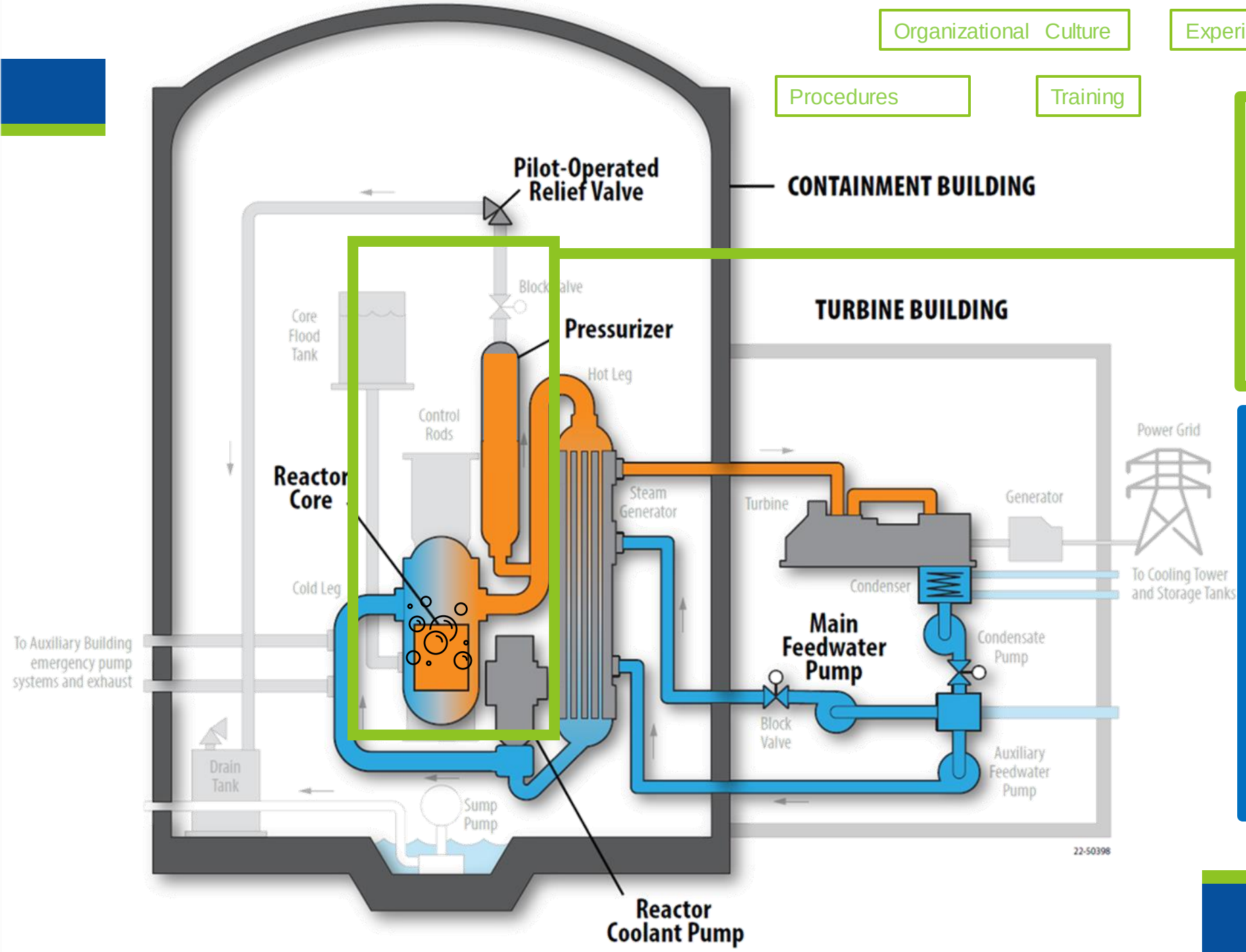
- Primary system reaches saturation conditions
- Primary coolant is boiling

Organizational Culture

Experience and Expectations

Procedures

Training



Level in Primary System is persistently high

- Due to boiling of coolant
- Countercurrent flooding

Operators continue to interpret pressurizer level as reliable indication of primary inventory per

- Their training
- Experience in the
- There is no direct indication reactor coolant level

Organizational Culture

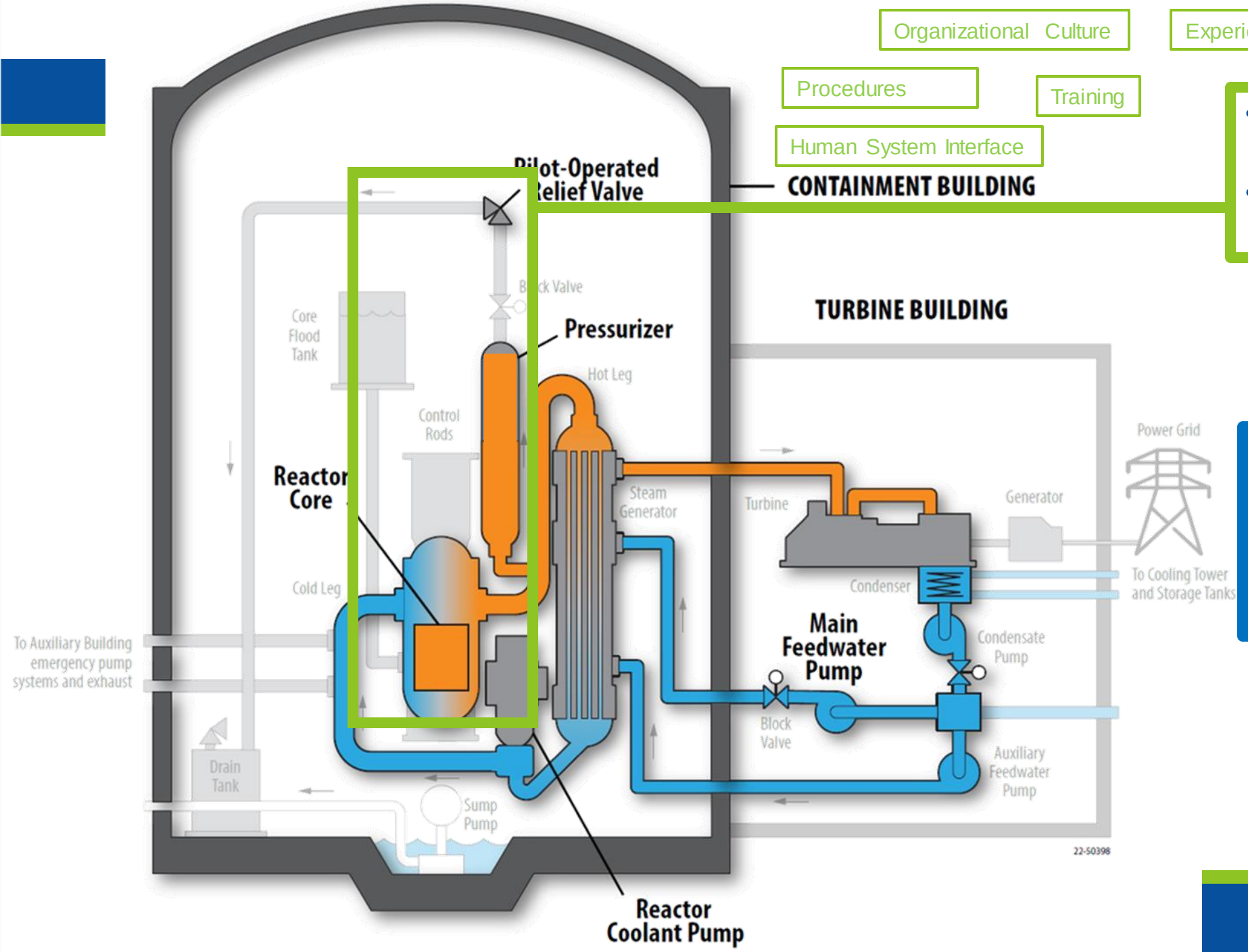
Experience and Expectations

Procedures

Training

Human System Interface

- Level in primary System remains high
- Pressure remains low



- Operators continue to think system is about to “go solid”, so they throttle the HPI pumps

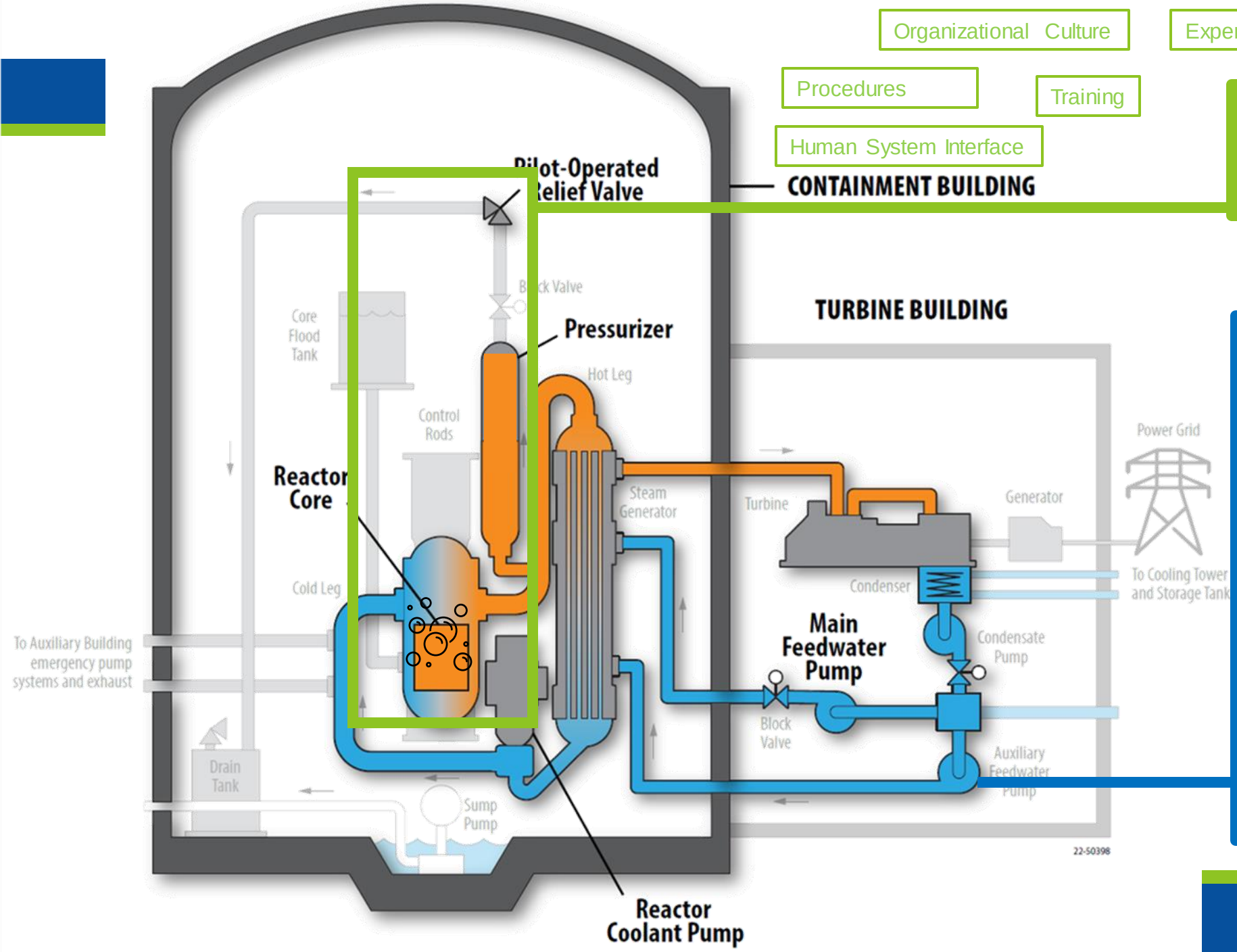
Organizational Culture

Experience and Expectations

Procedures

Training

Human System Interface



- Level in Primary System increases
- Pressure is dropping

- 8 minutes in, a supervisor from UNIT 1, comes in and notices block valves are closed on aux feed pumps, operators open them
- The closed block valves don't directly affect the accident progression, but distract and confuse operators

Organizational Culture

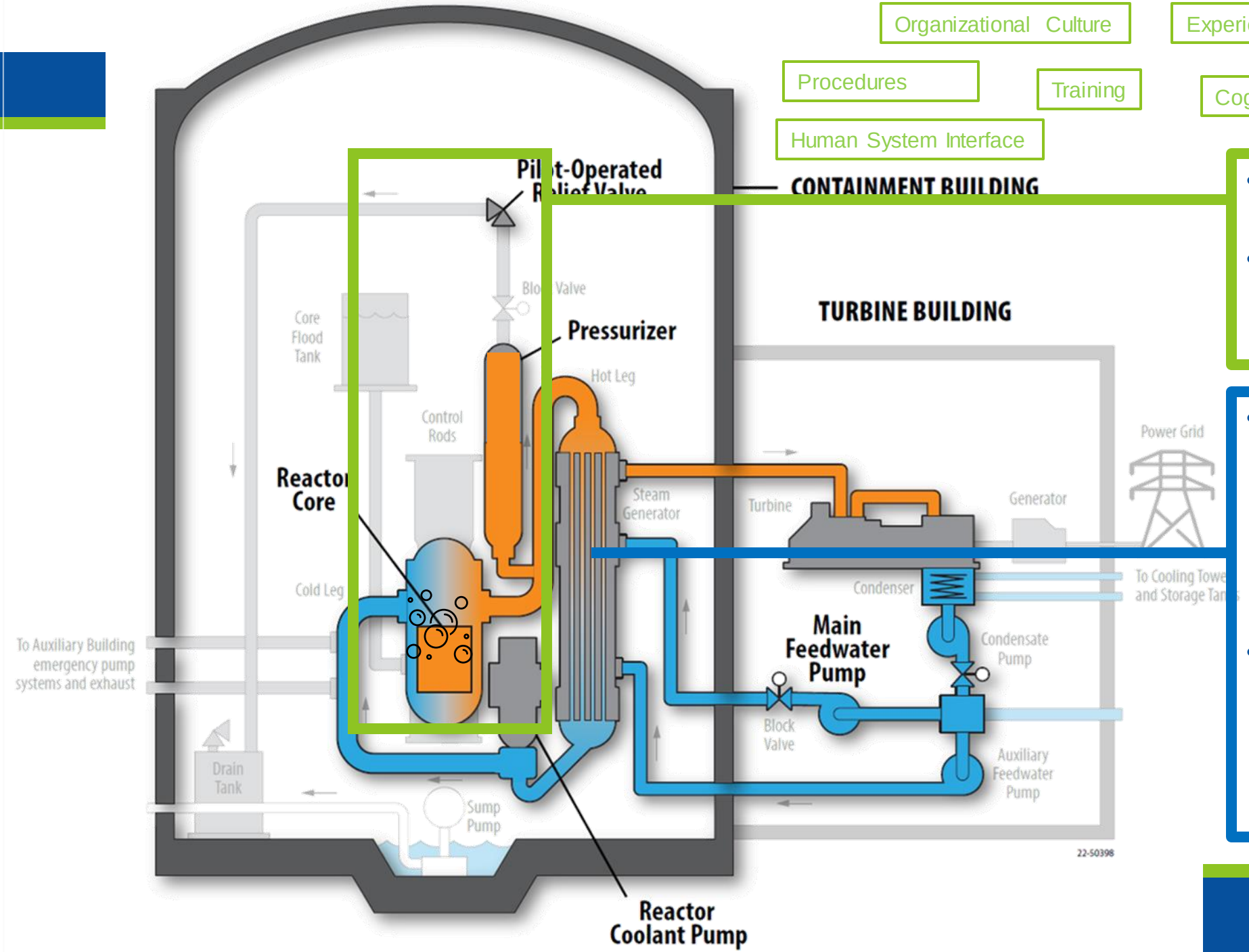
Experience and Expectations

Procedures

Training

Cognitive Biases

Human System Interface



- Level in Primary remains high
- Pressure remains low

- Operators interpret the low pressure as a primary-to-secondary leak due to thermal shock in the steam generator
- Operators subsequently misinterpret many indications of a LOCA in this way

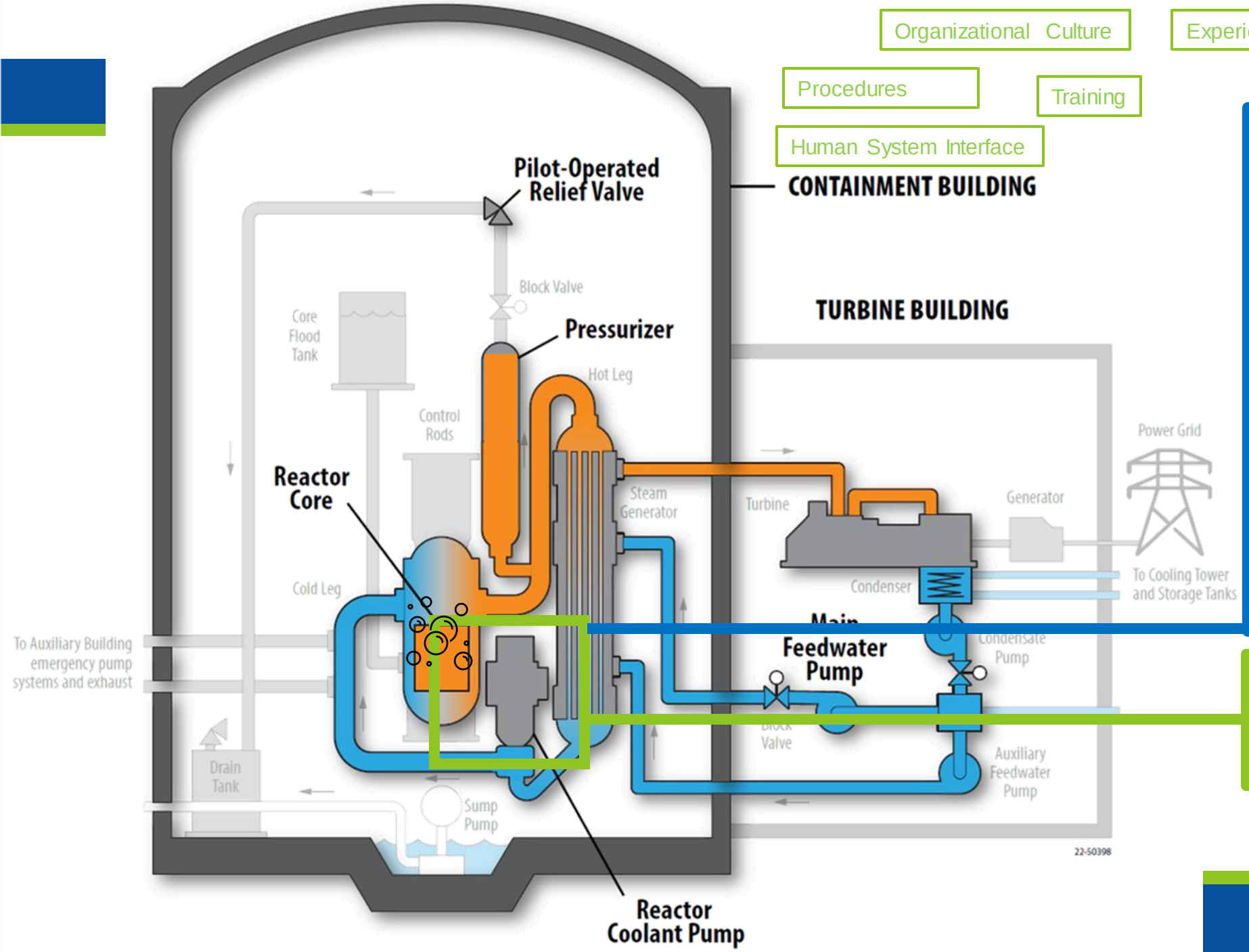
Organizational Culture

Experience and Expectations

Procedures

Training

Human System Interface



- Still confused by the barrage of inconsistent indications and concerned about the primary system level and pump vibrations, operators turn off the reactor coolant pumps in accordance with pump operating limits

Reactor coolant pumps are vibrating due to low pressure

Cognitive Biases

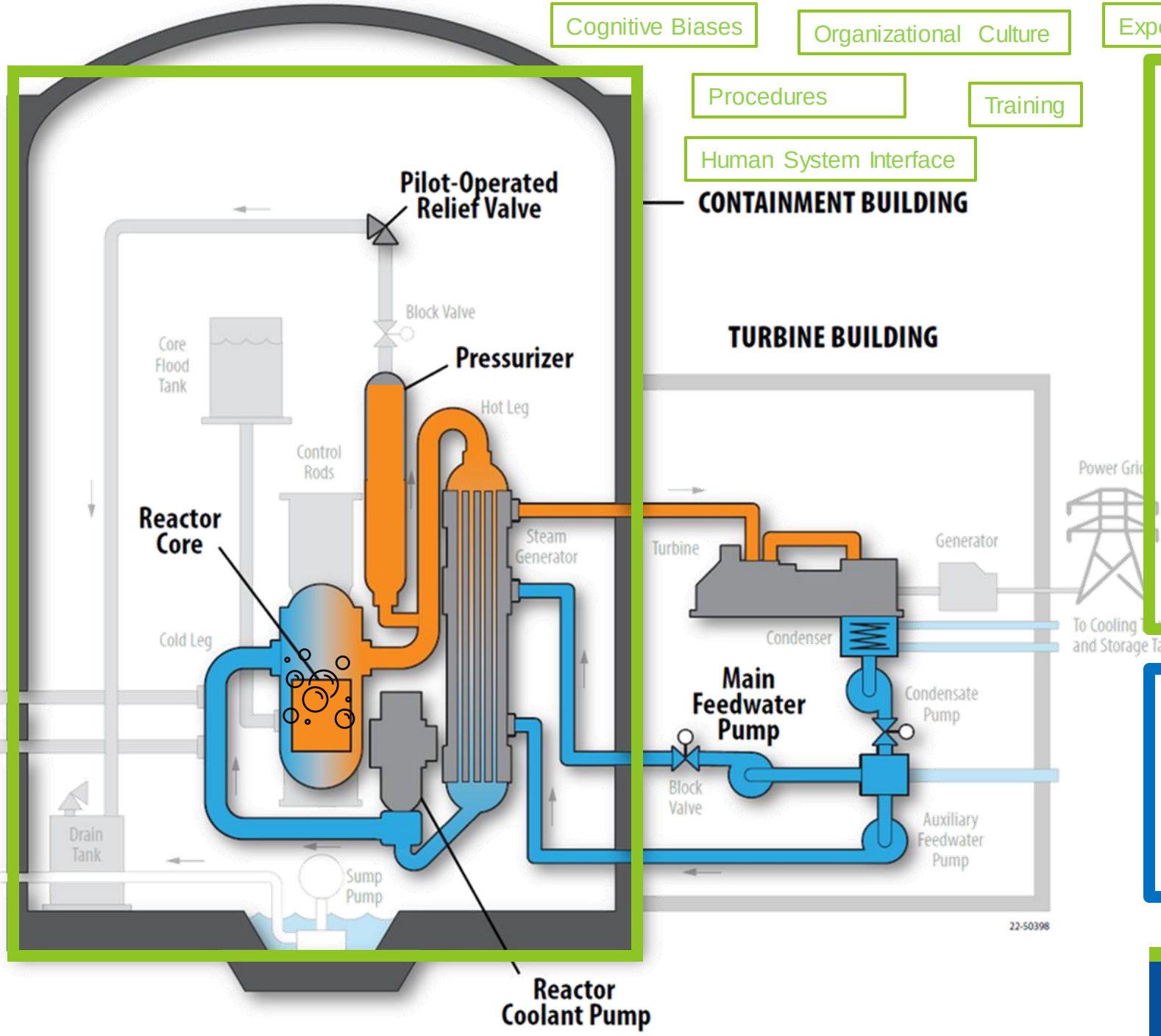
Organizational Culture

Experience and Expectations

Procedures

Training

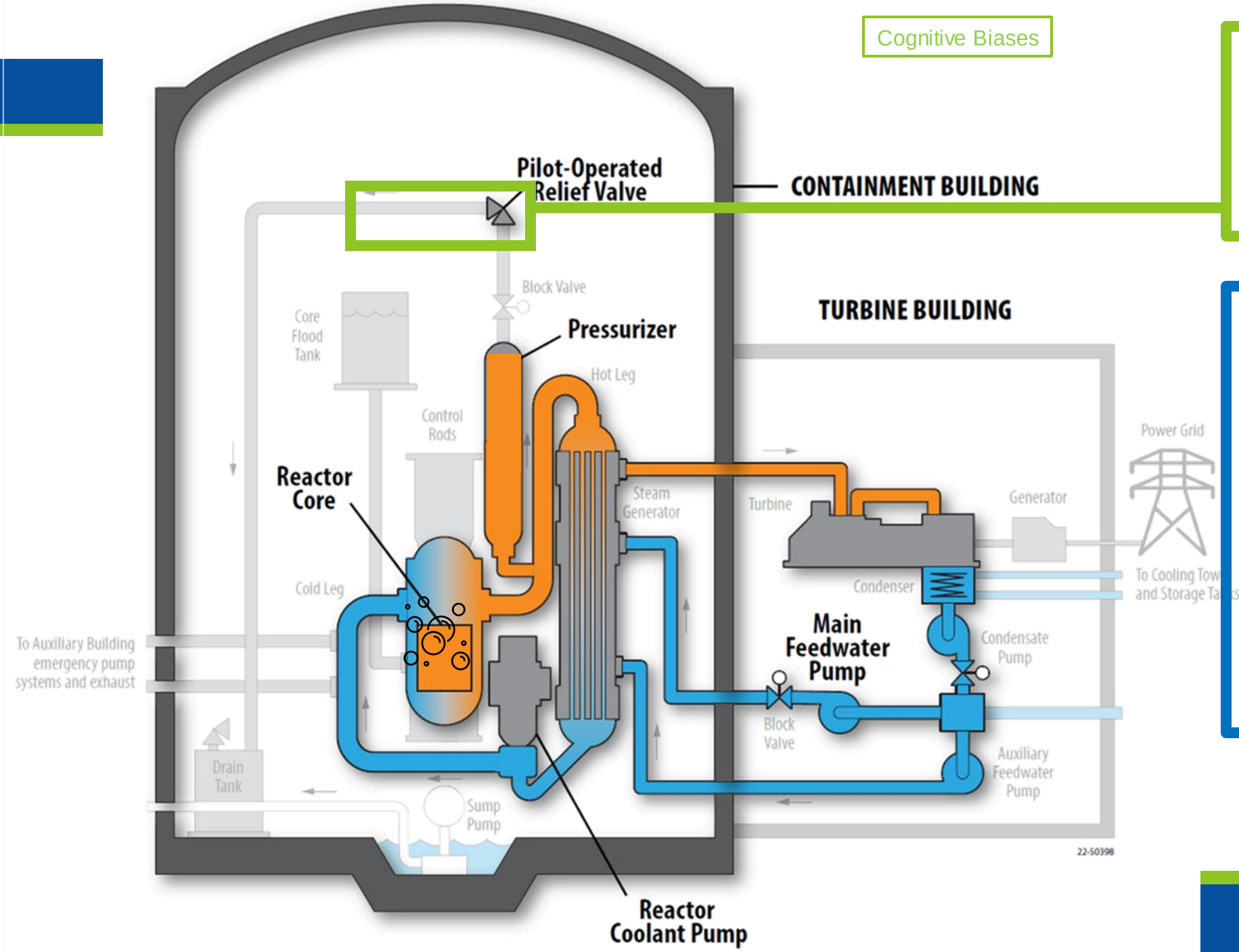
Human System Interface



- Without coolant flow from the Reactor coolant pumps, the primary temperature increases leading to a core meltdown
- Steam floods the containment building
  - Increasing containment pressure, temperature, radiation

- Operators continue to misinterpret indications that would point to a LOCA

Cognitive Biases

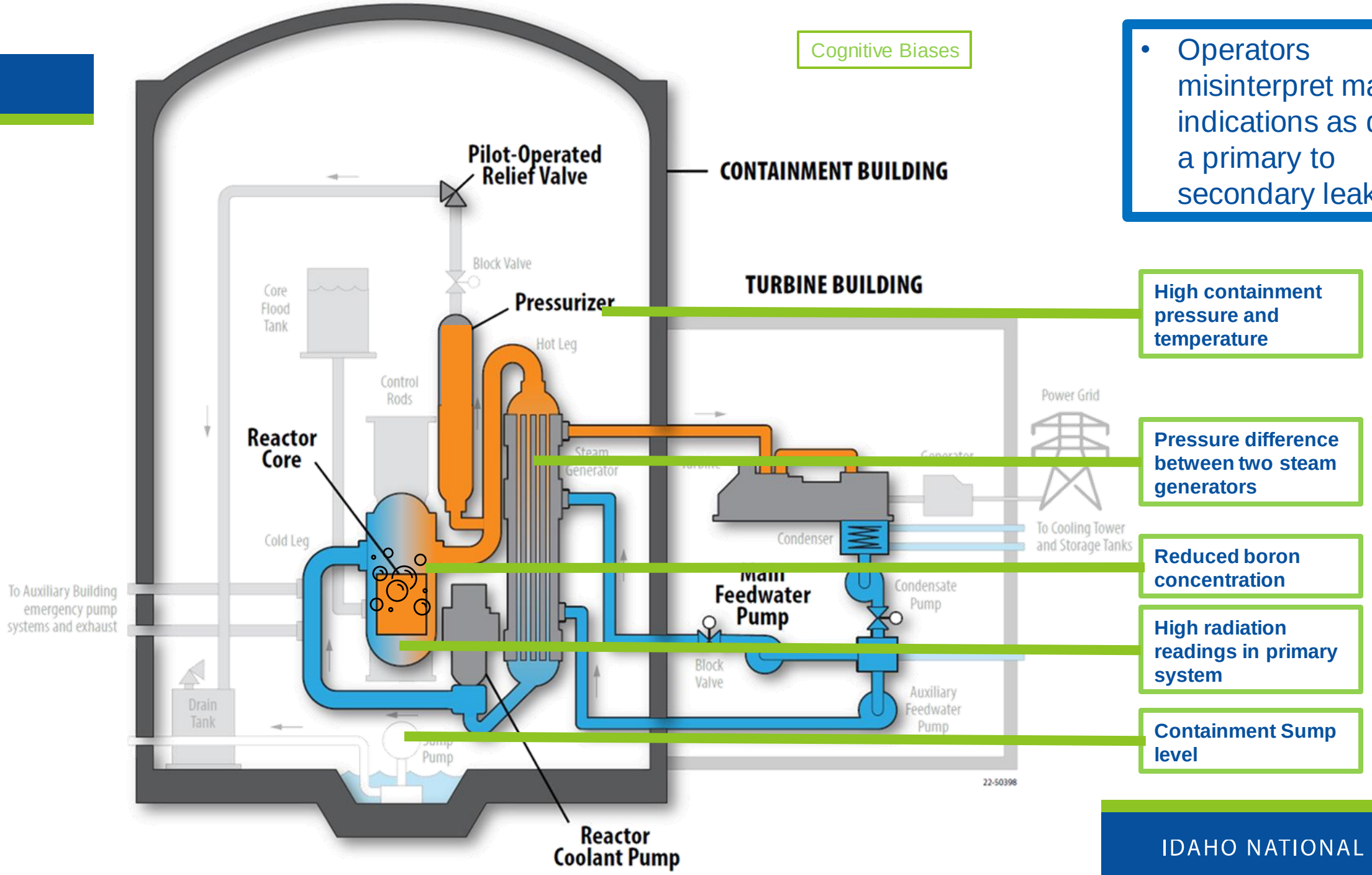


Temperature readings on relief valve discharge are high, indicating loss of coolant through valve

- Operators dismiss this citing the chronic PORV leakage
- Immediately prior to the event, an operator was performing boron dilution as a response to chronic leakage through PORV

Cognitive Biases

- Operators misinterpret many indications as due to a primary to secondary leak



High containment pressure and temperature

Pressure difference between two steam generators

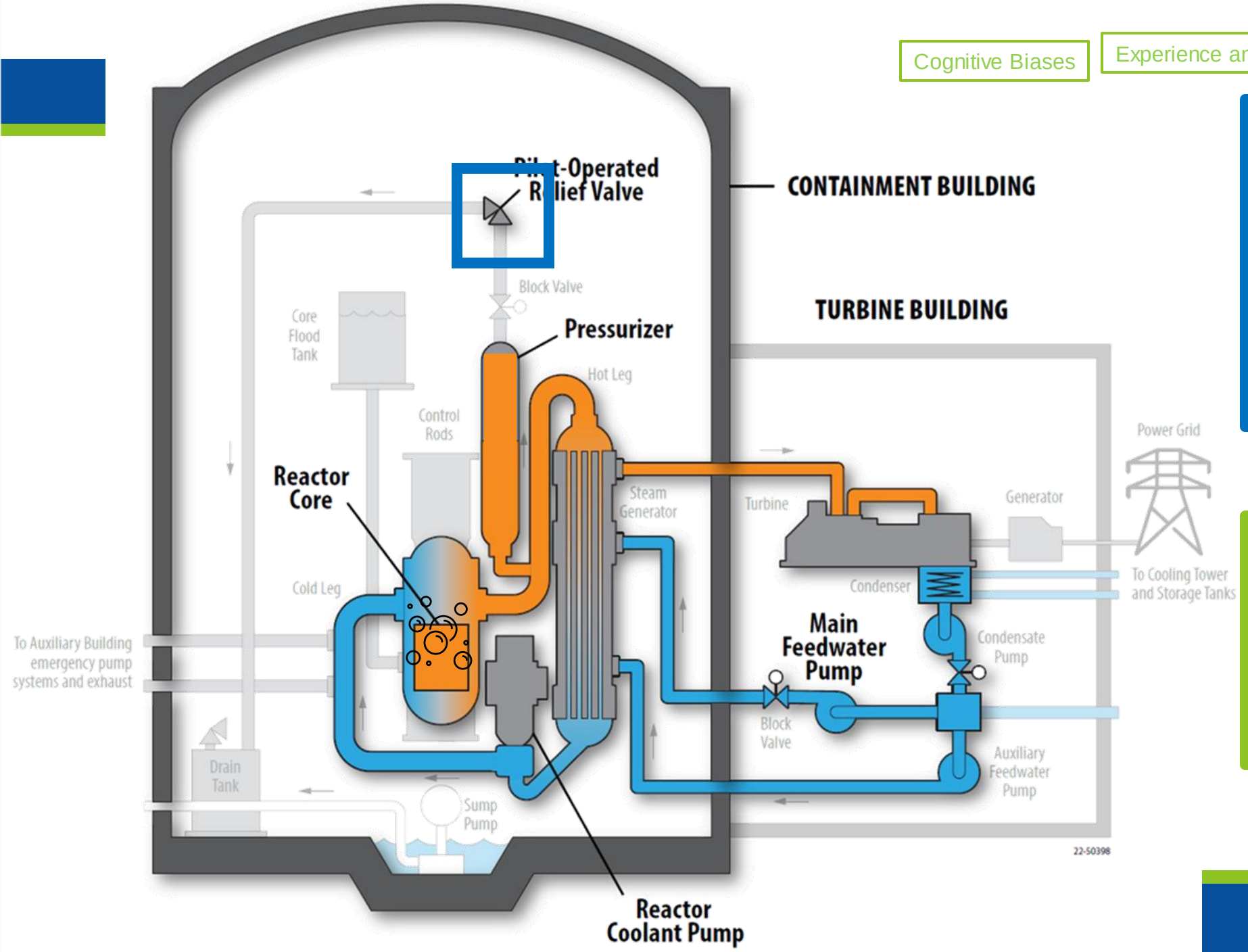
Reduced boron concentration

High radiation readings in primary system

Containment Sump level

Cognitive Biases

Experience and Expectations



A Shift supervisor comes in to relieve the previous one, and identifies the stuck open PORV valve and the operator close the the block valve, ending the LOCA

LOCA is resolved, it is many hours before operators can initiate coolant flow through the system to start to resolve the event

Some more context on operator mindset

According to Joyce, J. and Lapinsky, G. (1983),

- When preconceived notions about plant behavior do not correspond to actual plant conditions, several things may happen.
  - Operators may tend to repeat their original, inappropriate information-gathering strategy.
  - In order to try to make actual conditions fit their preconceived notions, people often selectively disbelieve or disregard anomalous information.
- When it becomes obvious that the situation does not fit their mental model, they regress to less effective forms of information gathering, for example, attending to all information regardless of its importance--looking for any clue at all that may be helpful.
  - Information overload usually results, further degrading the reasoning process.
  - Sub optional strategies such as information queuing, the dropping out of information, and cognitive fixation are the common under such conditions of stress and overload.

Summary of Human Factors in TMI

- Organizational Culture
  - Failure to learn from operational experience
    - Davis Besse
    - Beznau
    - Oconee-3
    - TMI-2
      - PORV stuck open in a previous incident
- Design
  - Operational philosophy was to prioritize avoiding reactor trip by using PORV, which led to frequent PORV actuation
- Maintenance
  - Failure to correct known issues with condensate polishing system and leaky PORV
  - Large number of systems out of service

Summary of Human Factors in TMI

- Human System Interface
  - Missing indications
  - Misleading indications
  - Obscured indications
- Training
  - Training focused on normal conditions, but failed to prepare operators for the conditions they encountered
    - Training and procedures were valid for liquid, but not for saturation conditions
  - Strong emphasis on avoiding letting the pressurizer go solid made operators fixate on wrong problem
    - This came from the reactor designer, the site operations and training, and many of the operators' Navy experience
- Experience and Expectations
  - Complacency associated with leaky PORV and actuation of HPI under "normal conditions"
  - Cognitive biases associated with interpretation of indications
  - Operators persisted in wrong interpretation despite contradictory evidence
    - This isn't their fault, it is how ALL humans work

What does this mean for the future?

- Thankfully, we learned a lot from TMI
  - Sharing of Operating Experience
  - Improved Procedures
  - Improved Training
    - Including simulators
  - Staffing improvements
    - Shift Technical Advisor
  - Improved indication
    - Safety Parameter Displays
    - Human factors evaluation
    - Direct indication of reactor coolant level
- We have implemented these lessons learned along with many more, and have an excellent safety record in the nuclear industry because of it

What does this mean for the future?

- The nuclear industry is poised to build new systems based on some of the assumptions established by existing systems
- We must remain vigilant in ensuring we understand the assumptions we are making, and that we do not violate them

https://www.flickr.com/photos/thirdwaythinktank/37875478862/in/album-72157665372889289/

Thank you!

- Questions?
- Katya.leblanc@inl.gov

References

- The Davis Besse Nuclear Power Plant Three Mile Island Accident Precursor Event. Mike Derivan, 2014
- Insights from the Three Mile Island accident—Part 1: The accident. William E. Burchill Nuclear News. 2019
- *Three Mile Island: A Report to the Commissioners and to the Public*, M. Rogovin, director of Special Inquiry Group, U.S. Nuclear Regulatory Commission (Jan. 1980).
- Joyce, J. and Lapinsky, G. (1983). A history and overview of the safety parameter display system concept. IEEE Transactions on Nuclear Science, NS-30(1).

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.