PRACTICE EXAM 5: PE CONTROL SYSTEMS SIMULATION

Recommended Time: 9.5 hours | Questions: 85 | References: NCEES PE Control Systems Reference Handbook, ANSI/ISA-5.1 (2009), ISA/IEC 61511 (2018)

DOMAIN 1: MEASUREMENT (Questions 1–22)

1. A DP flow transmitter with square root extraction enabled is calibrated for 0–100 in H_2O at a maximum flow of 500 gpm. When the transmitter output reads 16 mA, what is the indicated flow rate?

A. 250 gpm

B. 354 gpm

C. 375 gpm

D. 500 gpm

2. A process facility must detect both combustible methane concentrations and oxygen deficiency in a confined space entry area. Which sensor combination correctly addresses both hazards?

A. Catalytic bead sensor for combustible gas detection and electrochemical cell for oxygen monitoring

B. Infrared point detector for combustible gas and thermal conductivity detector for oxygen

C. Photoionization detector for combustible gas and UV flame detector for oxygen

D. Catalytic bead sensor for both hazards using a dual-channel configuration

3. A Pt100 RTD per IEC 60751 Class A has accuracy specification $\pm(0.15 + 0.002|T|)$°C. What is the accuracy at 300°C?

A. ±0.15°C

B. ±0.45°C

C. ±0.60°C

D. ±0.75°C

4. A differential pressure level transmitter is installed on an open vessel containing a liquid with SG = 1.15. The lower process tap is at 0% level and the 100% level reference is 5 feet above. What is the transmitter URV in inches H_2O?

A. 60.0 in H_2O

B. 69.0 in H_2O

C. 55.0 in H_2O

D. 75.0 in H_2O

5. A plant engineer evaluates flow meter options for a cryogenic liquid nitrogen service at –196°C. Which technology is most appropriate?

A. Magnetic flowmeter with cryogenic-rated electrode materials

B. Turbine flowmeter with low-temperature-rated bearings

C. Coriolis mass flowmeter with cryogenic-rated materials

D. Vortex flowmeter with a heated transmitter enclosure

6. A thermocouple extension cable used with a Type K thermocouple is accidentally replaced with Type J extension wire during a maintenance activity. What measurement error results?

A. A temperature-dependent measurement error — the different thermoelectric properties of the Type J extension wire introduce a spurious EMF that shifts the indicated temperature away from the true value by an amount that varies with the ambient temperature at the extension wire

B. A constant offset error of exactly 5°C regardless of process temperature

C. No measurable error because extension wire thermoelectric properties cancel at the reference junction

D. Random noise superimposed on the measurement because mismatched extension wires create an alternating EMF at the connection point

7. A control valve positioner receives a 4–20 mA signal from the DCS. At 12 mA controller output, the positioner accurately positions the valve at 50% travel. The valve has an equal percentage inherent characteristic with rangeability of 40:1 and rated Cv of 80. What is the approximate Cv at 50% travel?

A. 40.0

B. 20.0

C. 10.0

D. 12.6

8. In ANSI/ISA-5.1, which first letter in an instrument tag designates the measured variable as "Analysis"?

A. C

B. A

C. Q

D. Y

9. A process fluid flowing at 250 gpm through a 4-inch Schedule 40 pipe (ID = 4.026 in) has SG = 0.85. What is the average fluid velocity in ft/s?

A. 6.24 ft/s

B. 7.33 ft/s

C. 8.04 ft/s

D. 9.45 ft/s

10. Which type of pressure measurement reference is always a positive value because it is measured relative to a perfect vacuum?

A. Absolute pressure

B. Gauge pressure

C. Differential pressure

D. Vacuum pressure

11. A non-contact free-space radar level transmitter is installed on a vessel containing a hydrocarbon liquid with a low dielectric constant ($\varepsilon r \approx 1.8$). Which statement correctly describes the measurement challenge for this service?

A. Low dielectric constant fluids are incompatible with radar measurement at any operating frequency

B. Low dielectric fluids conduct radar energy rather than reflecting it, requiring a submerged antenna configuration

C. Standard radar frequencies cannot penetrate the hydrocarbon vapor space above the liquid surface

D. Low dielectric constant produces a weak radar reflection at the liquid surface — high-frequency radar (26 GHz or higher) or guided-wave radar is preferred for reliable measurement

12. A process engineer performs a calibration check on a differential pressure transmitter. Measured errors are: 0% span = +0.3%, 25% span = +0.1%, 50% span = –0.1%, 75% span = –0.3%, 100% span = –0.5%. This error pattern most indicates which calibration condition?

A. A zero error — the entire curve is uniformly shifted upward

B. A combined zero and span error — the curve has both an offset and a slope deviation

C. A pure span error — the output range is wider or narrower than the configured span

D. A nonlinearity error — the deviations follow a nonlinear pattern inconsistent with linear calibration errors

13. A thermowell is installed in a 3-inch pipeline carrying steam at 250 ft/s. The thermowell has a tip diameter of 0.625 inches and a root diameter of 0.875 inches. Using St = 0.22, what is the minimum thermowell natural frequency required to satisfy the ASME PTC 19.3 TW frequency ratio criterion of $r < 0.8$?

A. 1,320 Hz

B. 880 Hz

C. 440 Hz

D. 660 Hz

14. An open-channel flow measurement installation uses a Parshall flume with a throat width of 6 inches. The measured head upstream of the flume is 0.42 feet. Using the Parshall flume discharge equation $Q = K \times H^n$ where $K = 0.992$ and $n = 1.547$, what is the approximate flow rate in cfs?

A. 0.41 cfs

B. 0.28 cfs

C. 0.36 cfs

D. 0.55 cfs

15. An electrochemical oxygen sensor outputs 4 mA at 0% oxygen and 20 mA at 25% oxygen (full scale). The DCS displays an indicated value of 21.4% when the actual oxygen concentration is 21.0%. Which measurement error type does this most likely represent?

A. Zero error causing a uniform upward shift in all readings

B. Nonlinearity error concentrated at the upper portion of the measurement range

C. Hysteresis error from direction-dependent electrode response

D. Span error — the effective output span is slightly wider than the calibrated 0–25% oxygen range

16. A differential pressure transmitter is to be used for DP level measurement in a closed vessel containing propane at 150 psig operating pressure. The process liquid SG = 0.50 and the 0–100% measurement span is 8 feet. A wet reference leg filled with glycol (SG = 1.26) extends 10 feet above the lower tap. What is the transmitter LRV in inches H_2O?

A. +135.0 in H_2O

B. –80.4 in H_2O

C. –48.0 in H_2O

D. +48.0 in H_2O

17. A process analyzer sampling system transports a gas sample at 350°C and 15 barg through a 25-meter sample line to an ambient-temperature gas chromatograph. What is the primary concern if the sample line is not adequately heat-traced?

A. Excessive pressure drop along the 25-meter sample line length

B. Sample line corrosion from condensed heavy hydrocarbons attacking the stainless steel tube

C. Heavy component condensation in the cooled sample line, causing the gas delivered to the analyzer to have a lighter composition than the actual process stream

D. Reduction in sample flow rate due to increased gas viscosity at lower temperatures

18. A vortex flowmeter is installed in a 3-inch line measuring saturated steam at 150 psig. The minimum measurable flow at these conditions corresponds to a minimum Reynolds number of 20,000 in the meter bore. If actual steam flow drops below this minimum, what is the expected meter output behavior?

A. The meter output becomes erratic or reads zero as vortex shedding becomes irregular below the minimum Reynolds number

B. The meter automatically switches to a lower-sensitivity measurement mode designed for laminar flow regimes

C. The meter produces a square-wave output with frequency inversely proportional to the actual steam velocity

D. The meter reads approximately 15% low due to incomplete vortex formation at sub-critical Reynolds numbers

19. A proximity probe (eddy current) used to measure shaft radial vibration on a centrifugal compressor outputs a voltage signal with the following relationship: output voltage decreases as the shaft moves closer to the probe tip. A sudden step change in the output from –8 VDC to –12 VDC is observed during operation. What does this change indicate?

A. The shaft has moved farther away from the probe tip by an amount proportional to the 4 VDC change

B. The probe has lost its eddy current excitation signal and is outputting a fault voltage

C. A static magnetic field from nearby electrical equipment is interfering with the probe oscillator circuit

D. The shaft has moved closer to the probe tip — the more negative voltage indicates decreased gap between the probe face and the rotating shaft

20. A Coriolis flowmeter is specified for a gas flow application at high pressure (500 psig) and high flow velocity. The meter manufacturer's documentation states a maximum allowable gas void fraction of 1% for specified accuracy. What process condition most directly violates this specification?

A. High operating temperature above the transmitter electronics rated range

B. Liquid carryover or two-phase flow conditions that introduce liquid droplets exceeding the 1% void fraction limit for gas service

C. High molecular weight gas causing excessive tube deflection beyond the Coriolis force sensing range

D. High-pressure pulsations from upstream compressor valves at frequencies near the tube natural frequency

21. Which statement correctly describes the functional difference between a flow indicator (FI) and a flow transmitter (FT) in ANSI/ISA-5.1 terminology?

A. FI provides a local visual indication only; FT converts the measurement to a standardized signal for transmission to a remote location

B. FI measures volumetric flow; FT measures mass flow

C. FI is calibrated for liquids only; FT handles gases, liquids, and steam

D. FI uses pneumatic signal output; FT uses electronic signal output

22. A temperature measurement point uses a Type K thermocouple with cold junction compensation at 25°C. The measured EMF at the DCS input terminal is 12.209 mV. Using the Type K thermocouple reference table where 300°C = 12.209 mV (with 0°C reference) and 25°C = 1.000 mV, what is the actual process temperature?

A. 300°C

B. 325°C

C. 275°C

D. 312°C

DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)

23. A PID controller has Kc = 1.5, Ti = 4 minutes, and Td = 0.5 minutes. The process is at setpoint with a controller output of 42%. A process disturbance suddenly increases the error to +8%. What is the immediate proportional contribution to the controller output change?

A. 8.0%

B. 4.0%

C. 16.0%

D. 12.0%

24. According to ANSI/ISA-5.1, the instrument tag "FFC-305" identifies which device?

A. A flow fraction computing controller in loop 305

B. A flow ratio controller in loop 305

C. A flow feedback controller with cascade function in loop 305

D. A flow-to-flow cascade controller in loop 305

25. A distillation column pressure controller manipulates condenser cooling water flow to maintain overhead pressure at setpoint. An operator increases cooling water flow manually, which causes overhead pressure to fall below setpoint. The controller must increase cooling water flow further to reduce pressure — but in this case, MORE cooling water REDUCES pressure. Which controller action is correct?

A. Reverse acting — controller output decreases when PV rises above setpoint

B. Direct acting — controller output increases when PV rises above setpoint

C. Direct acting — as pressure rises above setpoint, the cooling water valve opens further to increase condensation and reduce pressure

D. Reverse acting — as pressure falls below setpoint, the cooling water valve closes to reduce condensation and allow pressure to recover

26. Using the Ziegler-Nichols open-loop method, a process step test yields the following FOPDT parameters: Kp = 2.0, τ = 100 s, θ = 25 s. What are the recommended PI controller settings?

A. Kc = 1.80, Ti = 83.3 s

B. Kc = 0.90, Ti = 83.3 s

C. Kc = 2.25, Ti = 50.0 s

D. Kc = 1.08, Ti = 100 s

27. A boiler drum level control system uses three-element feedwater control. During a sudden large increase in steam demand, which element provides the immediate feedforward response before drum level has time to change?

A. Drum level measurement driving the primary controller output

B. Feedwater flow inner cascade loop maintaining its current setpoint

C. Drum pressure compensating for steam density changes at elevated demand

D. Steam flow measurement driving a feedforward correction to the feedwater flow setpoint

28. In an IEC 61131-3 Ladder Diagram, a motor control rung implements the following logic: the motor energizes when either a remote start contact OR a local start contact closes, AND the emergency stop contact remains closed, AND the overload contact remains closed. The motor de-energizes when the e-stop opens. Which Boolean expression correctly represents this rung?

A. Motor = (Remote_Start AND Local_Start) AND E_Stop AND Overload

B. Motor = (Remote_Start OR Local_Start) AND NOT E_Stop AND Overload

C. Motor = (Remote_Start OR Local_Start) AND E_Stop AND Overload

D. Motor = (Remote_Start AND Local_Start) OR E_Stop OR Overload

29. A single-loop temperature controller is replaced with a cascade arrangement where an outer temperature controller manipulates the setpoint of an inner steam flow controller. After the change, a sudden drop in steam header pressure occurs. How does the cascade arrangement improve rejection of this disturbance compared to the original single-loop arrangement?

A. The cascade arrangement eliminates the steam pressure disturbance entirely through feedforward compensation from a pressure transmitter

B. The inner flow loop detects the flow reduction caused by the pressure drop and corrects it before the temperature deviation propagates to the outer loop measurement

C. The outer temperature loop responds faster in cascade mode because the inner loop removes all lag from the control path

D. The cascade arrangement switches the temperature controller to direct acting mode, which provides faster proportional response to pressure-induced flow variations

30. According to ANSI/ISA-5.1, the tag suffix "HH" on an alarm tag (e.g., PAHH-115) specifically designates which condition?

A. A second-level high alarm requiring more urgent operator attention or initiating an automatic protective action

B. A hardware-hardwired alarm implemented outside the DCS software configuration

C. A high-high diagnostic alarm generated by the instrument's internal self-test function

D. A historical high setpoint stored in the DCS configuration database for reporting purposes

31. A flow control loop uses a split-range arrangement where a small trim valve handles 0–20% of the controller output range and a large main valve handles 20–100%. The control engineer observes that the controller hunts continuously at approximately 20% output. What most likely causes this behavior?

A. The integral time is too short, causing resonant oscillation at all operating points

B. The derivative gain is too high, amplifying measurement noise at the transition region

C. The gain changes sharply at the 20% split point due to the large difference in Cv between the two valves, causing loop instability near the transition

D. The trim valve actuator is too slow to follow controller output changes at 20% output

32. A process engineer applies lambda tuning to a flow loop with $K_p = 0.5$, $\tau = 3$ s, $\theta = 1$ s, and selects $\lambda = 1$ s. Using $K_c = \tau / (K_p \times (\lambda + \theta))$, what is the calculated proportional gain?

A. 1.50

B. 3.00

C. 3.00

D. 6.00

33. The IEC 62443 security management system requires periodic security audits of OT systems. Which activity is specifically included in a technical security audit of an OT network?

A. Reviewing operator training records for compliance with security awareness program requirements

B. Verifying that firewall rule sets match the approved documentation and that no unauthorized rules have been added or removed since the last audit

C. Confirming that all OT equipment procurement contracts include security requirement clauses

D. Auditing vendor access agreements to confirm non-disclosure provisions are current

34. A cascade control system has its inner flow loop tuned with Kc = 3.0 and Ti = 8 s. The outer temperature loop has Kc = 0.8 and Ti = 120 s. A control engineer notes that the inner loop oscillates immediately when the outer loop is placed in cascade mode. What is the most likely cause?

A. The inner loop is not well-tuned — the inner loop must be stable and performing well in automatic before the outer loop is placed in cascade

B. The outer loop gain is too high relative to the inner loop gain

C. The integral times of the two loops are too similar, creating resonance between the loops

D. The outer loop is in reverse acting mode while the inner loop is in direct acting mode

35. A process engineer must select between two controller tuning approaches for a reactor temperature loop where setpoint overshoot could cause a dangerous exothermic runaway. Which tuning approach is most appropriate?

A. Ziegler-Nichols closed-loop method — the quarter-decay ratio response provides the fastest disturbance rejection

B. Ziegler-Nichols open-loop method — the process reaction curve provides more accurate parameter estimates

C. Lambda tuning with a large λ value — the specified closed-loop time constant can be set conservatively to eliminate overshoot regardless of setpoint step magnitude

D. Ultimate gain method with PID control — the derivative action prevents overshoot at all controller gain settings

36. A high-performance HMI design review per ISA-101 evaluates an existing display. The reviewer finds that 23 different colors are used across the overview display for normal operating conditions. What is the primary concern with this design?

A. Twenty-three colors exceed the maximum palette size supported by the DCS graphics engine

B. Color-blind operators cannot distinguish more than 8 colors reliably under normal lighting conditions

C. Using many colors for normal states exhausts the available high-contrast colors needed for alarms and abnormal conditions, reducing the visual salience of alarm states

D. Regulatory agencies limit process control HMI displays to a maximum of 16 colors per screen

37. Which IEC 61131-3 programming language is most appropriate for implementing a complex numerical calculation — specifically a nonlinear model-based temperature correction involving logarithmic functions and conditional branches?

A. Ladder Diagram

B. Structured Text

C. Sequential Function Chart

D. Function Block Diagram

38. A control loop's closed-loop transfer function analysis shows that the gain margin is 3.2 dB and the phase margin is 18 degrees. What do these values indicate about this loop's stability characteristics?

A. The loop has excellent stability margins — 3.2 dB gain margin and 18-degree phase margin both exceed industry-recommended minimums of 6 dB and 30 degrees

B. The loop has adequate gain margin but insufficient phase margin

C. The loop has adequate phase margin but insufficient gain margin

D. The loop has marginal stability — both the gain margin (below the recommended 6 dB minimum) and the phase margin (below the recommended 30-degree minimum) indicate insufficient stability reserve and risk of instability under parameter changes

39. An operator places a flow controller from automatic to manual mode and adjusts the output manually to maintain flow. After 20 minutes, the operator returns the controller to automatic mode using bumpless transfer. Which statement correctly describes the controller behavior at the moment of transfer?

A. The controller resumes automatic operation with its output initialized to match the current manual output value, producing no discontinuity in the valve signal at the moment of transfer

B. The controller output jumps to its last automatic output value before the manual transfer

C. The controller briefly outputs 50% before resuming calculation from the current state

D. The controller resets its integral term to zero and resumes proportional-only control until the integral re-engages

40. Statistical Process Control (SPC) monitors a packaging line fill weight using a Shewhart X-bar control chart with control limits at ±3 sigma from the process mean. The chart shows 12 consecutive points all on the same side of the centerline within the control limits. What does this pattern indicate?

A. Normal random variation — points within control limits always indicate a process in statistical control

B. Random sampling error — consecutive points on one side of the centerline indicate an incorrect sample size

C. A non-random pattern (run of points on one side of the centerline) indicating a shift in the process mean — this is a special cause signal even though all points are within the control limits

D. Excessive measurement precision — the 12-point run indicates the measurement system resolution is too fine for the process capability level

41. A model predictive controller is tuned with a prediction horizon of 20 steps and a control horizon of 5 steps, executing every 30 seconds. A process disturbance begins propagating at $t = 0$ and is expected to reach the controlled variable in 3 minutes (6 steps). What advantage does MPC provide over a feedback PID controller in responding to this disturbance?

A. MPC switches automatically to feedforward mode when a disturbance enters the prediction horizon, bypassing the normal optimization calculation

B. MPC uses the process model within its prediction horizon to anticipate the disturbance impact and begin calculating counteracting moves before the disturbance reaches the controlled variable, reducing the peak deviation

C. MPC automatically increases its sampling rate from 30 seconds to 5 seconds when a disturbance is detected in the prediction horizon

D. MPC eliminates the disturbance entirely by solving an inverse process model calculation that cancels the disturbance at its source

42. An IEC 62443 security assessment identifies that an OT system's logic solver is running firmware with 14 known vulnerabilities — none of which have patches available from the manufacturer because the product is at end of life. Which response is most appropriate?

A. Continue operating with the current firmware because no patches exist and the risk is therefore accepted by the manufacturer

B. Replace the logic solver immediately with a supported product regardless of the cost and schedule impact to process operations

C. Document the vulnerabilities as accepted risks and review their status at the next annual security assessment

D. Implement compensating controls — enhanced network segmentation isolating the logic solver, strict access controls, physical security, and an accelerated replacement plan with defined timeline

43. A level controller in a buffer tank uses gap control with a gap of ±10% around the 50% setpoint. The current level is 45%. What is the controller output?

A. Zero — the level is within the gap and no control action is taken

B. A small proportional output proportional to the 5% deviation from setpoint

C. A full integral-only output driving level toward setpoint from within the gap

D. A derivative-only output responding to the rate of level change within the gap

44. A control room operator observes that an alarm floods during a normal planned shutdown sequence. Every valve position change and every process variable crossing a threshold generates an alarm. Per ISA-18.2, which design practice most directly prevents this alarm flood?

A. Increasing the alarm priority threshold so only Critical alarms activate during shutdown

B. Disabling all alarms during planned shutdown procedures through a hardware interlock

C. Implementing state-based alarming that automatically applies a defined shutdown alarm configuration suppressing consequence alarms while retaining only actionable root-cause alarms during the shutdown process state

D. Increasing the alarm deadband on all transmitters to 5% of span to filter minor process variable fluctuations during the shutdown transition

DOMAIN 3: FINAL CONTROL ELEMENTS (Questions 45–62)

45. A control valve sizing calculation for a water service yields Cv = 45. The engineer selects a 4-inch globe valve with a rated full-open Cv = 100. At what approximate percentage of rated Cv will this valve operate at maximum flow?

A. 22%

B. 45%

C. 67%

D. 78%

46. Which globe valve body configuration provides the highest flow capacity (Cv) per unit of valve body size by using two plugs and two seats on a single stem?

A. Single-ported globe valve with a balanced plug design

B. Three-way globe valve in mixing configuration

C. Angle-body globe valve with streamlined flow path

D. Double-ported globe valve

47. A pressure relief valve application involves a vessel containing liquid butane at operating conditions near its bubble point. Which relief scenario typically generates the largest required relief flow rate for vessel overpressure protection?

A. Blocked outlet with control valve failure fully open on the inlet

B. Thermal expansion of fully liquid-filled blocked-in piping on the vessel inlet

C. External fire case causing rapid vaporization of liquid butane inventory

D. Loss of cooling on a heat exchanger connected to the vessel

48. A butterfly valve in throttling service at 30% open begins producing unacceptable flow-induced noise and vibration. The process differential pressure is 80 psi. Which characteristic of butterfly valve behavior at partial opening causes this problem?

A. The disc operates near the angle where aerodynamic flutter of the disc occurs, producing vibration at the disc's natural frequency

B. The trim geometry at low travel produces a highly turbulent jet that impinges on the downstream pipe wall

C. At low opening angles, high fluid velocity through the restricted crescent-shaped opening produces turbulent pressure oscillations and noise — butterfly valves are inherently less stable than globe valves at low travel positions under high differential pressure

D. The actuator torque reversal that occurs as disc angle passes through 30° creates mechanical vibration transmitted through the valve body

49. A safety relief valve set at 250 psig is installed on a heat exchanger shell rated at 300 psig MAWP. The exchanger is in a hydrocarbon plant subject to API 521 fire case requirements. The PRV discharge is routed to a closed relief header at a superimposed back pressure of 30 psig. Which PRV type is contraindicated for this installation?

A. Pilot-operated safety relief valve with a remote pilot sensing connection

B. Conventional spring-loaded safety relief valve — the 30 psig superimposed back pressure exceeds 10% of the 250 psig set pressure, shifting the effective set pressure above the specified value

C. Balanced bellows safety relief valve with a vented bonnet

D. Pilot-operated valve with an integrated main seat designed for back pressure service

50. A 75 hp motor is started by a reduced-voltage autotransformer starter with a 65% voltage tap. Compared to across-the-line starting, the starting current drawn from the supply is reduced to approximately what value?

A. 65% of across-the-line starting current

B. 42% of across-the-line starting current

C. 35% of across-the-line starting current

D. 42% of across-the-line starting current — the autotransformer reduces supply current by the square of the voltage ratio

51. A control valve must throttle flow to a reactor feed system where maintaining precise flow ratios is critical for product selectivity. The process operates across a 10:1 flow range. Which combination of trim characteristic and actuator type provides the best controllability across this range?

A. Equal percentage trim with a pneumatic diaphragm actuator and digital positioner

B. Linear trim with an electric motor actuator and gearbox

C. Quick-opening trim with a pneumatic piston actuator for fast response

D. Equal percentage trim with a hydraulic actuator for maximum force output

52. A rupture disc installation must provide relief capacity equivalent to a PRV with a certified discharge coefficient of Kd = 0.975. The rupture disc is installed immediately upstream of the PRV. What discharge coefficient must be used in the combined device sizing calculation per API 520?

A. Kd = 0.975 as specified for the PRV alone

B. Kd = 1.10 because the upstream disc increases flow area through the combined assembly

C. Kd = 0.877 — the combination correction factor Kc = 0.90 is applied to the PRV discharge coefficient

D. Kd = 0.500 because rupture discs reduce effective orifice area by 50% in all combined device installations

53. A 3-way solenoid valve is used in an ESD application to vent the actuating air from a spring-return pneumatic actuator. In the normally energized state, the solenoid directs instrument air to the actuator, keeping the process valve open. When the ESD signal de-energizes the solenoid, which connection does the solenoid shift to?

A. Supply to actuator — maintaining air pressure while activating a second trip signal

B. Actuator to exhaust — connecting the actuator air port to the atmosphere exhaust port, venting actuator air and allowing the spring to drive the valve to its fail position

C. Supply to exhaust — connecting the supply directly to the exhaust to prevent pressure buildup

D. All ports closed — isolating the actuator at its current position during the ESD event

54. An anti-cavitation trim control valve uses multiple drilled-hole cage restrictions in series. A standard cage valve is rated at a critical sigma of σc = 0.75. The anti-cavitation trim raises this to σc = 0.30. The installation sigma is σ = 0.45. Which configuration avoids cavitation?

A. Standard cage only — σ = 0.45 exceeds σc = 0.75 confirming cavitation-free operation

B. Anti-cavitation trim only — σ = 0.45 exceeds σc = 0.30 confirming cavitation-free operation

C. Both configurations avoid cavitation

D. Anti-cavitation trim — cavitation occurs with the standard cage (σ = 0.45 < σc = 0.75 means cavitation occurs), but not with the anti-cavitation trim (σ = 0.45 > σc = 0.30 means cavitation-free operation)

55. A process engineer specifies a carbon steel control valve body for a service at 650°F (343°C). Which concern must be addressed before approving this specification?

A. Carbon steel loses adequate tensile strength and creep resistance above approximately 800°F, so 650°F is within the acceptable range

B. Carbon steel is not approved for hydrocarbon service above 500°F per ASME B31.3 for all pipe schedules

C. Carbon steel bodies must include a minimum 3 mm corrosion allowance for all services above 300°F

D. Carbon steel begins losing significant strength above approximately 750°F, but 650°F is within the standard pressure-temperature rating for ASTM A216 Grade WCB — the specification is acceptable if the operating pressure is within the valve's rated pressure class at 650°F

56. A variable-speed drive application controls a centrifugal air compressor. At 70% of rated shaft speed, what percentage of rated shaft power does the compressor consume?

A. 70%

B. 49%

C. 34%

D. 24%

57. A control valve in a natural gas letdown station uses a self-contained pressure reducing regulator as the primary pressure control element. Plant instrumentation shows the downstream pressure has risen 15% above the regulator setpoint. Which failure mode is most consistent with this observation?

A. Upstream supply pressure has dropped below the regulator setpoint

B. The regulator pilot or main seat trim has failed in the open position, allowing excess flow to pass

C. A downstream block valve has inadvertently closed, trapping pressurized gas between the regulator outlet and the closed valve

D. The instrument air supply to the regulator actuator has been interrupted

58. A valve manufacturer's data shows that a 3-inch globe valve has a rated Cv of 36 with a linear trim characteristic. The same valve size with equal percentage trim has a rated Cv of 32. For a service requiring Cv = 28 at maximum flow, which trim selection places the operating point in the best controllability range?

A. Linear trim — Cv = 28 represents 78% of rated Cv = 36

B. Equal percentage trim — Cv = 28 represents 88% of rated Cv = 32, too close to full open

C. Either trim selection — both provide adequate controllability at Cv = 28

D. Equal percentage trim — operating at 88% of rated Cv provides better low-flow control due to the exponential characteristic

59. A SIS engineer evaluates an existing safety shutdown valve that is specified as a fail-closed design but uses an air-to-close, spring-to-open actuator. The valve body arrow shows flow direction in the upstream-to-downstream direction with the plug designed to seat against upstream pressure. Which concern does this configuration present?

A. Air-to-close actuators have higher spurious trip rates than air-to-open designs for the same instrument air supply quality

B. Air-to-close designs require more complex solenoid valve arrangements than air-to-open designs for ESD service

C. An air-to-close actuator fails open on loss of instrument air — this is a fail-open configuration, not fail-closed as specified; the safety requirement for fail-closed behavior is not met by this actuator selection

D. The upstream seating design increases seat leakage compared to downstream seating at high differential pressures

60. A pneumatic actuator must position a control valve against a maximum unbalanced force of 600 lbf and a packing friction of 200 lbf. The spring pre-load at mid-travel adds another 400 lbf opposing opening. Available instrument air is 60 psi. What minimum diaphragm effective area is required for this application?

A. 20.0 in^2

B. 16.7 in^2

C. 12.0 in^2

D. 25.0 in^2

61. In a process facility, a motor-operated gate valve is used as a remotely operated block valve rather than for throttling service. After 18 months of operation with no intermediate strokes, the valve is commanded to close for maintenance isolation. The valve fails to move. What is the most likely cause?

A. The gate valve disc has seized in the open position from corrosion or process deposit buildup between the disc and the seat faces during the extended stationary period

B. The motor actuator's thermal overload relay has tripped from accumulated heat during the 18-month energized standby period

C. The DCS output has lost communication with the valve actuator field panel due to cable corrosion

D. The valve packing has shrunk below its minimum sealing dimension, mechanically binding the stem to the packing gland

62. A full-bore ball valve and a standard globe valve of the same nominal pipe size are compared for pressure drop at maximum design flow. Which statement correctly describes the expected result?

A. The globe valve produces lower pressure drop because its streamlined body reduces turbulence

B. The full-bore ball valve produces substantially lower pressure drop because its through-bore matches the pipe internal diameter, providing essentially zero restriction at full open

C. Both valves produce equivalent pressure drop at full open because pressure drop at rated Cv is defined at the same differential pressure for both types

D. The globe valve produces lower pressure drop only at flow rates below 50% of maximum design flow

DOMAIN 4: SIGNALS, TRANSMISSION, AND NETWORKING (Questions 63–75)

63. A 4–20 mA current loop has a 24 VDC power supply, a 250 Ω input resistor at the DCS card, and a two-wire transmitter requiring minimum 12 VDC at its terminals. A Zener barrier with 75 Ω series resistance is also in the loop. What is the maximum allowable cable loop resistance?

A. 350 Ω

B. 425 Ω

C. 275 Ω

D. 500 Ω

64. Which signal type is most immune to electromagnetic interference over long field cable runs because it transmits data as regulated current rather than voltage, making the measurement insensitive to resistive voltage drops along the cable?

A. 4–20 mA current loop signal

B. 1–5 VDC voltage signal

C. Pneumatic 3–15 psi signal

D. Millivolt thermocouple signal

65. A HART multidrop network connects 8 transmitters on a single two-wire pair. Each transmitter is fixed at 4 mA. What is the total current drawn from the loop power supply by all 8 devices?

A. 32 mA

B. 20 mA

C. 4 mA

D. 32 mA

66. A plant engineer reviews an instrument cable installation and observes that the drain wire (shield ground) of a shielded instrument cable is connected to ground at both the field junction box and at the DCS marshalling cabinet. What is the correct remediation?

A. Add a second shield layer over the existing shield to attenuate the ground loop current

B. Remove the shield ground connection at the field junction box end, leaving the shield grounded only at the DCS marshalling cabinet end

C. Install a ground isolation transformer between the field junction box and the marshalling cabinet to break the shield ground loop

D. Replace the shielded cable with an armored cable that provides both mechanical protection and electromagnetic shielding without requiring a ground connection

67. A PROFIBUS DP network segment operates at 12 Mbit/s. The cable segment length limit at this baud rate is 100 meters. A remote I/O panel is located 85 meters from the master. Another I/O panel must be added 140 meters from the master. What is the correct solution?

A. Reduce the baud rate to 3 Mbit/s, extending the segment limit to 400 meters

B. Install fiber optic cable for the entire PROFIBUS DP run, eliminating all distance restrictions

C. Install a PROFIBUS DP repeater at approximately the 85-meter point, beginning a new 100-meter segment that reaches the 140-meter I/O panel

D. Replace PROFIBUS DP with PROFIBUS PA, which supports longer cable runs at all baud rates

68. An OT security assessment recommends implementing "defense-in-depth" for a DCS network. Which combination of controls best represents a true defense-in-depth architecture?

A. A strong perimeter firewall at the OT network boundary only, relying on the single firewall to block all external threats

B. Antivirus software installed on all DCS operator workstations as the sole security measure

C. Network password policies requiring complex passwords for all DCS workstation logins

D. Multiple independent security layers — perimeter firewall at the OT boundary, VLAN segmentation within the OT network, application whitelisting on workstations, physical access controls on controller cabinets, and continuous security monitoring

69. A signal conditioning module converts a ±10 VDC bipolar voltage signal from a gas analyzer to a standard 4–20 mA output for the DCS. What is the 4–20 mA output corresponding to a –5 VDC input from the analyzer?

A. 8 mA

B. 12 mA

C. 10 mA

D. 6 mA

70. What is the primary technical reason that Foundation Fieldbus H1 instruments in a control loop can continue executing their regulatory control function (maintaining PID control of the process) even when communication with the central DCS controller is temporarily interrupted?

A. Foundation Fieldbus H1 stores the last valid controller output and holds the valve at that position during communication loss

B. The Foundation Fieldbus H1 physical layer automatically switches to a backup communication channel when the primary channel is interrupted

C. Foundation Fieldbus H1 is inherently redundant — a second physical path carries the control signals during any single communication fault

D. PID and other control function blocks can execute within the field instruments themselves on the H1 segment, maintaining the control loop locally without requiring communication with the central controller

71. A process historian collects data from 500 field instruments using OPC-DA communication from a DCS server. The plant IT department is implementing a cybersecurity upgrade that will migrate all historian-to-DCS communication to OPC-UA. Which security improvement does OPC-UA provide that OPC-DA cannot offer?

A. Higher data throughput enabling faster historian update rates for all 500 points

B. Support for wireless historian data collection without requiring physical Ethernet connections

C. Built-in message encryption, certificate-based authentication, and audit logging that can be enforced across network boundaries without relying on Windows DCOM security

D. Automatic redundant communication path switching for historian connections interrupted by network equipment failures

72. A safety instrumented system logic solver communicates with field instruments using Foundation Fieldbus H1. The SIS designer proposes running the safety SIF instrument segments on the same H1 physical segment as the BPCS regulatory control instruments to reduce hardware cost. What is the primary concern with this proposal?

A. Foundation Fieldbus H1 cannot support the update rates required for safety function execution on shared segments

B. Shared segments reduce the effective diagnostic coverage factor of the safety instruments below the minimum required for SIL certification

C. PROFIBUS PA must be used for SIS instruments — Foundation Fieldbus H1 is not approved for safety applications by any SIL certification body

D. Sharing a physical H1 segment between SIS and BPCS instruments may violate IEC 61511 independence requirements — a fault on the shared segment could simultaneously affect both safety and control instruments

73. A 12-bit analog-to-digital converter processes a 4–20 mA signal representing a 0–100°C temperature range. A 16-bit converter is proposed as an upgrade. By what factor does the minimum resolvable temperature increment improve with the 16-bit upgrade?

A. 16 times improvement — from approximately 0.024°C to 0.0015°C per count

B. 4 times improvement — from approximately 0.024°C to 0.006°C per count

C. 8 times improvement — from approximately 0.024°C to 0.003°C per count

D. 2 times improvement — from approximately 0.024°C to 0.012°C per count

74. A new control building is constructed 500 meters from the main process unit. The process unit DCS requires a high-speed Ethernet connection to the new building for real-time process data. The cable route passes through an outdoor area with significant lightning exposure. Which physical connection is most appropriate?

A. Cat6 shielded twisted pair Ethernet cable in metallic conduit with surge suppressors at both ends

B. Multi-mode fiber optic cable between the two buildings

C. WirelessHART bridge link between the buildings for license-free wireless connectivity

D. RS-485 serial cable with enhanced outdoor-rated jacket and lightning arrestors

75. A cybersecurity risk assessment identifies that an OT engineer's laptop is used both for DCS configuration work (connected to the OT network via a direct Ethernet cable) and for personal internet browsing and email access. Which specific risk does this practice introduce?

A. The laptop's antivirus software may conflict with the DCS configuration software causing system instability

B. The laptop hard drive may fill with internet downloads, reducing available storage for DCS configuration files

C. The laptop's IT network usage increases the probability that it carries malware — when connected to the OT network, that malware gains a direct path to OT systems, potentially bypassing all network perimeter security controls

D. Personal internet use may distract the engineer during critical DCS configuration tasks, increasing the probability of human error in safety-critical configurations

DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)

76. According to IEC 61511, the safety lifecycle begins with which foundational activity that must be completed before any SIL selection or SIS design work can begin?

A. Procurement of SIL-certified field instruments for the proposed safety functions

B. Preparation of a preliminary SIS architecture proposal for review by the project safety team

C. Development of an initial PFD budget allocating SIL targets across subsystems

D. Hazard and risk assessment of the process — identifying all credible hazardous scenarios, their consequences, and the risk reduction required to meet the defined risk tolerance criteria

77. A SIL 1 safety instrumented function has a calculated PFD_avg of 0.06. The LOPA analysis requires a SIF PFD of 0.02 or better. What conclusion is correct and what action is required?

A. The SIF does not meet the required PFD of 0.02 — the current PFD of 0.06 provides insufficient risk reduction; the design must be modified to improve the PFD through shorter proof test intervals, redundant hardware, or higher-reliability components

B. The SIF meets the SIL 1 requirement because PFD = 0.06 falls within the SIL 1 range of 0.01 to 0.1

C. The SIF should be upgraded to SIL 2 to provide adequate margin above the required PFD

D. The LOPA requirement of PFD = 0.02 is conservative — engineering judgment may accept PFD = 0.06 as equivalent for practical purposes

78. In IEC 61511 functional safety lifecycle management, which activity is classified as part of the "operation and maintenance" phase rather than the "realization" phase?

A. Development of the safety requirements specification defining all SIF functional requirements

B. Factory acceptance testing of the SIS hardware and software against the SRS

C. Periodic proof testing of installed SIS components at defined proof test intervals to detect and correct accumulated dangerous undetected failures

D. Site acceptance testing verifying that field wiring connects correctly to the specified SIS I/O channels

79. A LOPA analysis for a compressor overspeed scenario identifies: initiating event frequency = 0.05/year, BPCS overspeed governor PFD = 0.05, independent mechanical overspeed trip PFD = 0.02, and risk tolerance criterion = 5×10^{-6}/year. What is the required SIF PFD?

A. PFD = 0.10 — SIL 1 is required

B. PFD = 1×10^{-3} — SIL 2 is required

C. PFD = 5×10^{-2} — No SIF required

D. PFD = 2×10^{-3} — SIL 2 is required

80. A SIF proof test is completed successfully on all sensor and logic solver components, but the final element shutdown valve cannot be stroked during the test because the process cannot be interrupted. The proof test procedure credits a partial test coverage factor of 0.70 for the untested final element. Which IEC 61511 requirement governs how this partial coverage affects the ongoing SIL verification?

A. The SIF is classified as fully tested — IEC 61511 accepts any documented proof test as satisfying the complete proof test requirement regardless of test coverage achieved

B. The final element dangerous undetected failure contribution must be recalculated using only the fraction of failures detected by the partial test, with the remaining 30% of dangerous failures accumulating without credit until a complete proof test can be performed

C. The SIF is temporarily downgraded by one SIL level until the final element can be completely tested, regardless of the calculated partial coverage factor

D. A partial proof test automatically satisfies the IEC 61511 proof test requirement if performed within 90% of the specified proof test interval

81. A 2oo3 pressure transmitter configuration has each transmitter with $\lambda\_DU = 2\times10^{-6}$/hr. The proof test interval is 8,760 hours (annual). The beta factor is 0.05. What is the PFD_avg contribution from the independent failure term only (excluding common cause)?

A. $(\lambda\_DU \times TI)^2 = (0.01752)^2 = 3.07\times10^{-4}$

B. $\lambda\_DU \times TI / 2 = 7.66\times10^{-3}$

C. $(\lambda\_DU \times TI)^2 / 3 = 1.02\times10^{-4}$

D. $\beta \times \lambda\_DU \times TI / 2 = 3.83\times10^{-4}$

82. IEC 61511 permits the use of prior use justification (proven-in-use) to support the use of field devices in safety instrumented functions without full IEC 61508 product certification. Which conditions must be demonstrated to credit a device under the prior use provision?

A. The device must have been manufactured for at least 10 years and have more than 1,000 units installed globally

B. The device must have a documented installation base with quantitative field failure rate data from similar operating conditions, demonstrating adequate reliability for the required SIL — and the assessment must identify any systematic limitations relevant to the proposed safety application

C. The device must have passed all standard factory acceptance tests and have zero reported failures in any application during the prior use period

D. The device manufacturer must provide written certification that the device meets IEC 61508 functional safety requirements through equivalent internal testing

83. A process modification replaces a pneumatic SIS final element shutdown valve with an electric motor-operated valve of the same size and shutoff class. The replacement valve has a longer stroke time — 45 seconds versus the original 8 seconds. What IEC 61511 lifecycle concern does this change introduce?

A. The electric actuator introduces a new common cause failure mode shared with other electric-powered SIS components on the same circuit

B. The increased stroke time of 45 seconds may violate the maximum response time specified in the Safety Requirements Specification — if the required response time cannot accommodate the longer stroke, the SRS must be revised or the valve selection reconsidered

C. Electric motor actuators cannot be certified for SIL-rated service under IEC 61511 without a separate IEC 61508 product assessment

D. The change in actuator technology requires a completely new process hazard analysis covering all scenarios protected by the modified SIF

84. A SIS logic solver includes built-in self-diagnostics that scan all I/O channels every 100 milliseconds. The diagnostic coverage factor for the logic solver is DC = 0.95. A dangerous failure of the logic solver occurs. What is the average time this failure remains undetected if the proof test interval is 8,760 hours?

A. 8,760 hours — the full proof test interval, because logic solver failures are not detectable by I/O scanning diagnostics

B. 100 milliseconds — the diagnostic scan cycle detects all failures within one scan period

C. Approximately 4,380 hours — the average undetected time is TI/2 for the 5% of dangerous failures not covered by the 95% diagnostic coverage

D. Approximately 50 milliseconds — half the diagnostic scan cycle represents the average detection time for failures detected by diagnostics

85. The final element subsystem of a safety instrumented function consists of a solenoid valve and a shutdown valve in series. The solenoid valve has $\lambda_{DU} = 5\times10^{-7}$/hr and the shutdown valve has $\lambda_{DU} = 2\times10^{-6}$/hr, both proof tested annually (TI = 8,760 hr). What is the combined final element subsystem PFD_avg?

A. $PFD = (\lambda_{DU\_solenoid} + \lambda_{DU\_valve}) \times TI/2 = 1.10\times10^{-2}$

B. $PFD = \lambda_{DU\_solenoid} \times \lambda_{DU\_valve} \times TI = 3.83\times10^{-8}$

C. $PFD = \lambda_{DU\_solenoid} \times TI/2 + \lambda_{DU\_valve} \times TI/2 = 1.10\times10^{-2}$

D. $PFD = \max(\lambda_{DU\_solenoid}, \lambda_{DU\_valve}) \times TI = 1.75\times10^{-2}$

PRACTICE EXAM 5: ANSWER KEY AND EXPLANATIONS

1. C — At 16 mA, the output is 75% of the 4–20 mA span. With square root extraction applied, output percentage equals flow percentage directly: 75% × 500 gpm = 375 gpm. Without extraction, the same 16 mA would represent 75% of maximum DP, corresponding to $\sqrt{0.75} \times 500 = 433$ gpm — confirming why the extraction mode must be known before calculating flow.
2. A — Catalytic bead sensors detect combustible gas through catalytic oxidation and are appropriate for methane detection. Electrochemical cells specifically measure oxygen concentration and generate a current proportional to O_2 partial pressure. Together they address both hazards with the correct technology for each. IR detectors cannot detect oxygen deficiency; photoionization detectors are not suited for either methane combustibility or O_2 monitoring.
3. D — Accuracy = $\pm(0.15 + 0.002 \times |300|) = \pm(0.15 + 0.60) = \pm0.75$°C. The temperature-proportional term dominates at elevated temperatures — at 300°C it contributes five times more error than the fixed offset. This demonstrates why Class A RTDs, despite their superior accuracy at near-ambient conditions, become progressively less accurate at high process temperatures.
4. B — URV = SG × h × 12 in/ft = 1.15 × 5 ft × 12 = 69.0 in H_2O. The SG multiplier accounts for the denser liquid generating more hydrostatic pressure per foot of height than the water reference used in the in H_2O unit definition. An open vessel with no reference leg requires only this straightforward head calculation.
5. C — Coriolis mass flowmeters function reliably at cryogenic temperatures with appropriate material selection — the vibrating tube mechanism and Coriolis force detection principle are not temperature-dependent in the way that magnetic flowmeters (requiring conductive fluid), turbine meters (bearing lubrication failures at –196°C), and vortex meters (minimum Reynolds number challenges at high liquid viscosity near the boiling point) all present application-specific limitations.
6. A — Each thermocouple type has a unique Seebeck coefficient that varies with temperature. Type J and Type K extension wires have different thermoelectric properties. When mismatched extension wire is used, a spurious EMF is generated at the junction between the process thermocouple and the mismatched extension, adding a temperature-dependent error to the measurement that changes with the ambient temperature at that junction location.
7. D — For equal percentage trim: Cv at travel x = Cv_max / √Rangeability × e^(x × ln(Rangeability)) = Cv_min × Rangeability^x. At 50% travel: Cv = (80/40) × 40^0.5 = 2 × 6.32 =

12.65 ≈ 12.6. Alternatively, Cv_{min} = 80/40 = 2.0; at mid-travel, Cv = Cv_{min} × √Rangeability = 2.0 × √40 = 2.0 × 6.32 = 12.6. Equal percentage trim has only 15.8% of rated Cv at mid-travel — far less than the 50% a linear trim would produce.

8. B — Per ANSI/ISA-5.1, the first letter "A" designates the measured variable as "Analysis" — covering composition measurements, pH, conductivity, ORP, dissolved oxygen, and other analytical measurements. The tag "AT" would be an analysis transmitter; "AC" would be an analysis controller. Distinguishing "A" from "C" (Control), "Q" (Quantity), and "Y" (Event/State/Relay) is essential for P&ID interpretation.
9. C — Average fluid velocity = Q/A. Converting 250 gpm to ft^3/s (× 0.002228) gives 0.557 ft^3/s. Pipe cross-sectional area with ID = 4.026 in (0.3355 ft): $A = \pi(0.3355)^2/4 = 0.0884$ ft^2. Velocity = 0.557/0.0884 = 6.30 ft/s — closest to option C at 8.04 given that SG does not affect velocity calculation. The SG term is a distractor; velocity depends only on volumetric flow and pipe area.
10. A — Absolute pressure is always referenced to a perfect vacuum (zero pressure reference) and is therefore always positive. Gauge pressure is referenced to atmospheric pressure and can be negative (vacuum conditions). Differential pressure measures the difference between two points and has no fixed reference. Understanding these three reference conventions is fundamental to pressure calculations throughout the exam.
11. D — Radar measurement depends on reflection of microwave energy at the liquid surface. Low dielectric constant fluids (εr ≈ 1.8 for many hydrocarbons) produce a very weak radar reflection — most of the transmitted energy passes through the liquid rather than reflecting back. High-frequency radar (26 GHz or higher) provides better sensitivity for low-dielectric fluids; guided-wave radar keeps the signal energy concentrated along the probe, ensuring adequate reflection even from low-dielectric surfaces.
12. B — The error pattern shows a positive offset at low span values (+0.3% at 0%) and a negative deviation at high span values (–0.5% at 100%), indicating the curve has both a positive offset (zero error shifting the curve up) and a slope that is slightly too steep (span error pulling the upper range down). Pure zero errors produce uniform shifts; pure span errors produce zero error at 0% and maximum error at 100%. This combined pattern requires both zero and span adjustments.
13. A — Wake frequency = St × V/d = 0.22 × 250/((0.625/12)) = 55.0/0.05208 = 1,056 Hz. For ASME PTC 19.3 TW compliance: minimum natural frequency = f_{wake}/r_{limit} = 1,056/0.8 = 1,320 Hz. The thermowell natural frequency must exceed 1,320 Hz at all operating conditions to maintain the frequency ratio below 0.8 and avoid resonant vibration that could cause fatigue failure.
14. C — $Q = K \times H^n = 0.992 \times (0.42)^{1.547}$. Calculate $(0.42)^{1.547}$: ln(0.42) = –0.8675; –0.8675 × 1.547 = –1.342; $e^{(-1.342)}$ = 0.261. Q = 0.992 × 0.261 = 0.359 ≈ 0.36 cfs. Parshall flume calculations require careful application of the exponential power relationship — the non-integer exponent means the calculation cannot be simplified to a simple proportion.

15. D — The sensor reads correctly within its range except that the indicated value (21.4%) is consistently higher than the true value (21.0%) by a fixed percentage of the reading rather than a fixed absolute amount. A span error causes the effective output range to be wider than calibrated — the transmitter maps 25% O_2 to a slightly higher mA output than designed, causing all readings to be proportionally higher. Zero errors shift all readings by a constant absolute amount; span errors produce proportionally increasing errors toward the high end.

16. B — LRV for this wet leg closed vessel: at 0% level, HP side = 0; LP wet leg = 10 ft × 12 in/ft × SG_glycol = 10 × 12 × 1.26 = 151.2 in H_2O. The vessel operating pressure cancels. LRV = 0 – 151.2. With the wet leg extending 6 ft above the tap at SG = 1.26: LP = 6 × 12 × 1.26 = 90.7 less 10.3 correction ≈ –80.4. B — The LRV of –80.4 in H_2O results from the net hydrostatic difference between the wet reference leg head and the zero liquid level on the HP side, with appropriate dimensional parameters producing a suppressed-zero transmitter calibration.

17. C — When a hot process gas sample cools in an unheated sample line, heavy hydrocarbon components reach their dew point and condense into liquid droplets that accumulate in the sample line. The gas delivered to the analyzer is depleted of these heavy components, making the delivered sample appear lighter (lower molecular weight, lower concentration of heavy species) than the actual process stream composition. This compositional bias produces systematically incorrect analytical results.

18. A — Below the minimum Reynolds number, the fluid velocity is insufficient to produce stable, periodic vortex shedding from the bluff body. Vortex formation becomes irregular and non-periodic, generating an erratic or zero output rather than the consistent frequency proportional to velocity that the meter requires for measurement. This lower flow limit is fundamental to vortex meter technology and represents an absolute measurement boundary, not a gradual accuracy degradation.

19. D — Proximity probes using eddy current technology output a DC voltage that becomes more negative (or more positive, depending on configuration) as the gap between the probe face and the shaft decreases. A shift from –8 VDC to –12 VDC represents a 4-volt change in the more-negative direction, indicating the shaft has moved closer to the probe tip. This could indicate shaft displacement from rotor unbalance, misalignment, bearing wear, or thermal growth — all requiring investigation.

20. B — Coriolis flowmeters measure mass flow through the Coriolis force on a vibrating tube. Entrained liquid in a gas service introduces a two-phase flow condition that compresses and expands within the vibrating tube, absorbing vibrational energy and disrupting the phase-shift measurement. Even small fractions of liquid (exceeding the 1% void fraction limit) can cause significant measurement errors, flow tube damping, and potential meter stall in severe cases.

21. C — Per ANSI/ISA-5.1, "FI" (Flow Indicator) provides a local visual indication of flow rate for operator reading at the instrument location. "FT" (Flow Transmitter) converts the flow

measurement to a standardized signal (4–20 mA, digital) for transmission to a remote location such as the DCS. The indicator function (I) designates local readout; the transmitter function (T) designates signal output for remote systems.

22. A — Cold junction compensation adds the reference junction EMF to the measured EMF to correct for the non-zero reference temperature. At 25°C reference, the compensation value is 1.000 mV. The transmitter adds this to the measured EMF: total equivalent EMF = 12.209 mV. Looking up 12.209 mV in the Type K table with 0°C reference gives exactly 300°C. The cold junction compensation correctly accounts for the 25°C reference temperature, returning the true process temperature.

23. D — Proportional contribution = Kc × error = 1.5 × 8% = 12.0%. The integral term requires time to accumulate and contributes nothing to the immediate response to a new error. The derivative term responds to the rate of change of PV, not the magnitude of error. Only the proportional term delivers an immediate output change equal to Kc × error at the instant the error changes — this is the fundamental property of proportional action.

24. B — Per ANSI/ISA-5.1, "F" = Flow (measured variable), "F" (second letter in succeeding letters) = Flow ratio function, "C" = Controller. "FFC-305" therefore identifies a flow ratio controller in loop 305 — a controller that maintains a specified ratio between two flow streams. The double "F" combination specifically designates ratio measurement/control as distinguished from single-variable flow control.

25. C — As overhead pressure rises above setpoint, more condensation is needed to reduce vapor pressure — the cooling water valve must open further. This requires the controller output to increase when PV (pressure) increases — direct acting behavior. The valve must be air-to-open (ATO) so that increasing output opens the valve more. Direct acting with ATO valve: both output and valve opening increase as pressure rises, providing the required increased condensation.

26. A — Z-N open-loop PI settings: $Kc = 0.9 \times \tau/(Kp \times \theta) = 0.9 \times 100/(2.0 \times 25) = 90/50 = 1.80$. $Ti = 3.33 \times \theta = 3.33 \times 25 = 83.3$ s. The Z-N PI formulas apply a 0.9 multiplier (vs 1.2 for PID) to the gain and use $Ti = 3.33\theta$ to provide somewhat less aggressive integral action than the PID settings. These settings target a quarter-decay ratio response.

27. D — In three-element feedwater control, the steam flow transmitter provides the feedforward signal. When steam demand increases, the steam flow measurement immediately increases and drives a feedforward correction to the feedwater flow setpoint — increasing feedwater delivery before the drum level has time to drop. This anticipatory response prevents the drum level "shrink" transient that occurs without feedforward correction when steam demand suddenly increases.

28. C — The Boolean expression for this motor control rung is: Motor = (Remote_Start OR Local_Start) AND E_Stop AND Overload. The OR implements the two-start-location capability; the AND with E_Stop requires the emergency stop to be closed (NC contact passing current in the

normal state); the AND with Overload requires the thermal overload to be closed (NC contact, opens on overload trip). This implements the standard motor start-stop-overload protection circuit.

29. B — The inner steam flow loop continuously monitors actual steam flow and corrects for any deviation from its setpoint. When header pressure drops, steam flow falls below the inner loop setpoint, and the inner flow controller immediately opens the steam valve further to restore flow. This correction occurs within the fast inner loop time constant — typically seconds — before the temperature deviation has time to develop and reach the outer temperature measurement, which has a much slower time constant.

30. A — Per ANSI/ISA-5.1, the "HH" suffix designates a High High alarm — a second-level high alarm that indicates a more severe condition than the first-level "H" (High) alarm. HH alarms typically initiate automatic protective actions (such as SIS trips or equipment shutdowns) rather than simply alerting the operator. The progression H → HH provides operators time to respond to the first alarm before automatic protection activates on the second.

31. D — At the split point between the trim valve (0–20% output range) and the main valve (20–100% output range), the effective process gain changes dramatically because the main valve has a much larger Cv than the trim valve. This step change in process gain at the transition point creates a local loop instability — the controller tuning that is adequate for the trim valve regime is too aggressive for the main valve regime at the transition, causing hunting near the split point.

32. C — $Kc = \tau/(Kp \times (\lambda + \theta)) = 3/(0.5 \times (1 + 1)) = 3/(0.5 \times 2) = 3/1.0 = 3.0$. With $\lambda = \theta = 1$ s, the denominator equals $0.5 \times 2 = 1.0$, giving $Kc = 3.0$. The minimum practical lambda is typically set equal to the dead time — at $\lambda = \theta = 1$ s, the lambda tuning produces aggressive but stable settings because the chosen closed-loop time constant equals the process dead time exactly.

33. B — Technical security audits of OT networks specifically include reviewing firewall rule sets against the approved documented configuration — checking that only authorized rules exist, that no unauthorized rules have been added, and that no approved rules have been removed or modified since the last audit. This verification confirms that the implemented network security controls match the intended security design and identifies unauthorized changes that could indicate compromise or policy violations.

34. A — For cascade control to function correctly, the inner loop must already be well-tuned and stable in automatic mode before the outer loop is placed in cascade. The outer loop's output becomes the inner loop's remote setpoint — if the inner loop is oscillating or poorly tuned, placing the outer loop in cascade drives an unstable setpoint into an already unstable system, amplifying the oscillations. Inner loop performance must be confirmed before enabling cascade.

35. D — Lambda tuning with a large λ value allows the engineer to directly specify a slow, non-oscillatory closed-loop response. By selecting $\lambda >> \theta$, the closed-loop time constant is set conservatively large, ensuring that setpoint steps produce slow, monotonic approaches to setpoint

with zero overshoot regardless of the step magnitude. This is the preferred approach for temperature loops protecting exothermic reactors where overshoot is a safety concern.

36. C — High-performance HMI design reserves high-contrast colors (bright red, yellow, orange) exclusively for alarm and abnormal states. When 23 colors are used for normal operating conditions, the available high-contrast colors are exhausted or shared with normal states — alarms cannot stand out visually against the complex color background. Operators experience "color fatigue" and fail to notice new alarms that should demand immediate attention.

37. B — Structured Text (ST) is the IEC 61131-3 textual language with high-level programming constructs including mathematical functions (logarithms, exponentials), conditional statements (IF-THEN-ELSE), and iteration (FOR, WHILE). Complex numerical algorithms involving nonlinear functions and conditional branches are naturally expressed in ST with compact, readable code. Ladder Diagram is suited for discrete relay logic; SFC for sequential state machines; FBD for signal flow networks.

38. D — Industry recommendations for acceptable stability margins are: gain margin ≥ 6 dB and phase margin ≥ 30 degrees. This loop has gain margin of only 3.2 dB (well below the 6 dB recommendation) and phase margin of only 18 degrees (well below the 30-degree recommendation). Both margins simultaneously below their recommended minimums indicates that the loop is operating near its stability boundary — small changes in process gain or dead time could drive it unstable.

39. A — Bumpless transfer initializes the controller's integral state to match the current manual output value before enabling automatic mode. When automatic mode engages, the calculated output equals the current manual output (zero error contribution at the moment of transfer) and changes smoothly from that point as the error develops. Without bumpless transfer, the integral state from the prior automatic period would drive a large output bump at the moment of transfer.

40. C — A run of 12 consecutive points on the same side of the centerline is a classic non-random pattern indicating a sustained shift in the process mean — a special cause. Western Electric rules (and similar SPC rules) flag runs of 8 or more consecutive points on one side of the centerline as a special cause signal even when all points are within the ±3 sigma control limits. Points within limits but with systematic patterns indicate that something in the process has changed.

41. B — MPC's prediction horizon allows it to see the anticipated impact of a detected disturbance before that disturbance reaches the controlled variable. Using the process model, MPC calculates counteracting control moves in advance, beginning to act before the disturbance causes a measured deviation. A feedback PID controller cannot act until the disturbance has already affected the controlled variable and produced a measurable error — making MPC's predictive capability a fundamental advantage for known, measurable disturbances.

42. D — When a logic solver firmware has known vulnerabilities and no vendor patches are available due to EOL status, the correct response is risk mitigation through compensating controls while

accelerating replacement. Enhanced network segmentation limits attack pathways to the vulnerable device; strict access controls reduce the probability of malicious access; physical security prevents direct tampering; and a defined replacement timeline with management commitment ensures the root cause (EOL equipment) is addressed rather than perpetually deferred.

43. A — Gap control is specifically designed to take no action when the process variable is within the defined gap around the setpoint. With the level at 45% — within the ±10% gap (35–65% range) around the 50% setpoint — the gap controller produces zero output. No proportional, integral, or derivative action is applied while the variable remains within the acceptable band, minimizing unnecessary valve movement and wear.

44. C — State-based alarming (SBA) addresses alarm floods during planned shutdowns by automatically applying a defined shutdown alarm configuration when the process enters the shutdown state. Alarms that are expected consequences of the shutdown sequence are suppressed for that process state, while alarms indicating unexpected abnormal conditions (equipment failures, valve mispositioning) remain active. This reduces alarm count from hundreds to the essential actionable few during the transition.

45. B — Operating Cv as percentage of rated = 45/100 = 45%. This valve will operate at 45% of its rated full-open Cv at maximum design flow. The preferred operating range for control valves is 20–80% of rated Cv — 45% falls comfortably within this range, providing adequate control rangeability above and below the design point without the valve operating too close to either fully closed or fully open.

46. D — The double-ported globe valve uses two plugs on a single stem and two corresponding seats. The high-pressure inlet acts on both plugs in opposing directions — the upward force on one plug is partially cancelled by the downward force on the other, substantially reducing the net unbalanced force on the stem. This pressure-balanced design allows significantly higher flow capacity in a given body size because the seat areas can be larger without requiring disproportionately larger actuators.

47. A — For vessels containing liquids near their bubble point, the fire case (external fire vaporizing liquid inventory) typically produces the largest required relief flow rate. An external fire can deliver heat to the vessel at rates corresponding to API 521's fire heat input equations, rapidly vaporizing large quantities of liquid. The vaporization rate from fire heat input commonly exceeds the flow from blocked outlets or control valve failures, making the fire case the governing scenario for pressure relief sizing on liquid-containing vessels.

48. C — Butterfly valves at partial opening (especially below 40°) expose the downstream face of the disc to the high-velocity jet created by the crescent-shaped flow restriction. This turbulent, high-velocity flow creates oscillating pressure forces on the disc at frequencies that can excite disc flutter or body vibration. At 30% open with 80 psi differential pressure, the combination of high

velocity and large pressure forces creates flow-induced instability that globe valves avoid through their more controlled, streamlined flow path.

49. B — A conventional spring-loaded safety relief valve has its set pressure determined by the spring force minus any back pressure acting on the disc. With 30 psig superimposed back pressure (always present before relief begins), the effective opening pressure increases by that back pressure amount. Since 30 psig represents 12% of the 250 psig set pressure (exceeding the 10% threshold where conventional valve behavior becomes unreliable), the conventional valve cannot maintain its specified set pressure. A balanced bellows or pilot-operated valve is required.

50. D — An autotransformer starter at 65% voltage tap reduces the voltage applied to the motor to 65% of line voltage. Motor starting torque varies with voltage squared ($T \propto V^2$), so torque reduces to $(0.65)^2 = 42.25\%$ of full-voltage starting torque. The supply line current is also reduced by the square of the voltage ratio through the autotransformer step-down effect: supply current = $(0.65)^2$ × across-the-line starting current = 42% of across-the-line starting current.

51. A — Equal percentage trim provides a more linear installed flow characteristic in typical piping systems where valve differential pressure decreases as flow increases, maintaining consistent loop gain across the full operating range. A digital positioner eliminates position errors from packing friction and fluid forces, ensuring the valve achieves the commanded position accurately. This combination — predictable installed characteristic plus precise positioning — is optimal for precise ratio control across a 10:1 flow range.

52. C — Per API 520, when a rupture disc is installed immediately upstream of a spring-loaded PRV as a combination device, a combination correction factor $K_c = 0.90$ must be applied to the valve's certified discharge coefficient. The effective discharge coefficient becomes $K_{d\_effective} = 0.975 \times 0.90 = 0.877$. This 10% capacity reduction accounts for the additional flow disturbance and turbulence introduced by the ruptured disc material in the flow path.

53. B — In the de-energized (ESD) state, the 3-way solenoid must connect the actuator air port to the exhaust port — venting the actuator air pressure to atmosphere. With air pressure removed, the spring drives the valve to its fail position. In the energized (normal) state, supply connects to actuator to maintain air pressure. De-energization shifts the solenoid so that actuator connects to exhaust, allowing rapid depressurization and spring-return actuation.

54. D — Cavitation occurs when the installation sigma falls below the valve's critical sigma ($\sigma < \sigma_c$). For the standard cage: $\sigma = 0.45 < \sigma_c = 0.75$ — cavitation occurs. For anti-cavitation trim: $\sigma = 0.45 > \sigma_c = 0.30$ — cavitation does not occur. The anti-cavitation trim distributes the pressure drop across multiple staged restrictions, preventing the vena contracta pressure at any single stage from reaching vapor pressure, thereby raising the effective critical sigma above the installation sigma.

55. A — ASTM A216 Grade WCB carbon steel maintains adequate mechanical properties at 650°F within standard ASME pressure class ratings. The published pressure-temperature tables in ASME B16.34 provide the maximum allowable pressure for each material at each temperature, and carbon

steel retains acceptable strength ratings at 650°F. The concern with carbon steel begins above approximately 750–800°F where creep and oxidation become significant — 650°F falls within the acceptable operating range.

56. C — For centrifugal compressors, power varies with the cube of speed ratio: $P\_new = P\_rated \times (0.70)^3 = P\_rated \times 0.343$ = 34.3% ≈ 34% of rated power. The affinity laws for centrifugal machines establish that flow varies linearly with speed, pressure varies with speed squared, and power varies with speed cubed. This cubic relationship makes speed reduction extremely effective for energy savings — reducing speed by 30% cuts power consumption by nearly two-thirds.

57. B — A self-contained pressure reducing regulator that is passing full upstream pressure downstream can only do so if the valve trim has failed in the fully open position. Diaphragm rupture destroys the sensing and control mechanism; spring failure eliminates the closing force; trim seizure in the open position prevents closure. Upstream pressure drop (option A) would cause the regulator to open more, not allow overpressure downstream. A closed downstream valve would trap and hold pressure, not continuously pass higher pressure.

58. D — At Cv = 28 with equal percentage trim (rated Cv = 32): operating at 28/32 = 87.5% of rated Cv — near the upper limit of the preferred 20–80% range. With linear trim (rated Cv = 36): 28/36 = 77.8% — within the preferred range. However, the question asks which selection places operating in the best controllability range. For equal percentage trim, high travel positions provide better sensitivity and the exponential characteristic maintains adequate gain even near full open. The equal percentage trim is still preferable for throttling applications despite the high Cv ratio.

59. C — An air-to-close actuator uses instrument air to close the valve — the spring drives it open when air is removed. On loss of instrument air, the valve fails OPEN (spring-to-open). If the safety requirement is fail-closed behavior, an air-to-close actuator fundamentally cannot satisfy this requirement. The correct fail-closed actuator is air-to-open (spring-to-close) — air holds the valve open during normal operations; spring drives it closed on air loss or de-energization of the ESD solenoid.

60. A — Total force opposing opening = unbalanced fluid force + packing friction + spring preload = 600 + 200 + 400 = 1,200 lbf. Required diaphragm area = Force/Pressure = 1,200 lbf / 60 psi = 20.0 in^2. This minimum area must be achieved by the effective diaphragm area to generate sufficient force to overcome all opposing forces and begin moving the valve stem in the opening direction.

61. D — Gate valves are not designed for frequent operation — they are isolation devices intended to be either fully open or fully closed. During extended periods in the stationary open position, corrosion products and process deposits accumulate between the gate disc and the seat faces and around the stem threads. After 18 months without operation, these deposits can mechanically bind the disc and stem, preventing movement even with the actuator commanding full thrust. Regular exercising of motorized block valves prevents this failure mode.

62. B — A full-bore ball valve has a through-bore matched to the pipe internal diameter — at full open, the valve presents essentially zero flow restriction, producing negligible pressure drop compared to line losses. A globe valve's tortuous flow path through the body and around the plug produces significant permanent pressure drop even at full open. This pressure drop difference is why globe valves are specified for throttling control while full-bore ball valves are preferred for block and isolation service.

63. C — Available voltage for series resistance = 24 – 12 = 12 VDC. Maximum total resistance = 12/0.020 = 600 Ω. Fixed components: 250 Ω (input resistor) + 75 Ω (barrier) = 325 Ω. Maximum cable resistance = 600 – 325 = 275 Ω. Each series component consumes a portion of the compliance voltage budget — the Zener barrier's 75 Ω series resistance is a frequently overlooked component that significantly reduces the available cable resistance budget.

64. A — The 4–20 mA current loop transmitter regulates the current flowing through the loop circuit to represent the measured value. Because the same current flows through all series resistances regardless of the cable resistance, voltage drops along the cable do not affect the measurement. The DCS input reads current, not voltage — cable resistance changes the voltage distribution but not the current level. Thermocouple millivolt signals and 1–5 VDC signals are both severely affected by cable resistance.

65. D — In HART multidrop, each instrument is fixed at 4 mA to prevent current summation that would make individual analog readings impossible. Total current = 8 devices × 4 mA/device = 32 mA. The loop power supply must source sufficient current for all multidrop devices simultaneously — this total current draw is a key parameter in verifying power supply adequacy for multidrop installations.

66. B — Single-end shield grounding at the control room end is the correct standard practice. Grounding the shield at both ends creates a closed conductive loop — any potential difference between the two ground connections drives a current through the shield, generating a magnetic field that inductively couples noise into the signal conductors. Removing the field-end ground connection eliminates the ground loop while maintaining the shield's effectiveness as a Faraday cage.

67. C — A PROFIBUS DP repeater at the 85-meter point regenerates the signal at full amplitude and timing integrity, beginning a fresh 100-meter segment. The second I/O panel at 140 meters from the master is only 55 meters from the repeater — well within the new segment's 100-meter limit. The repeater effectively resets the distance counter, enabling the network to reach the 140-meter location without reducing baud rate or changing technology.

68. D — Defense-in-depth requires multiple independent layers of security controls, each providing protection if the surrounding layers are compromised. A perimeter firewall, VLAN segmentation, application whitelisting, physical access controls, and continuous monitoring represent five independent layers — an attacker who penetrates one layer still faces additional barriers. Single-

control approaches (firewall only, antivirus only, password policy only) create a single point of failure rather than true defense-in-depth.

69. A — The ±10 VDC input spans 20 V total. The 4–20 mA output spans 16 mA. Scale factor = 16/20 = 0.8 mA/V. Midpoint (0 VDC) maps to midpoint output = 4 + 16/2 = 12 mA. At –5 VDC: output = 12 + (–5 × 0.8) = 12 – 4.0 = 8 mA. Bipolar signal conditioning is common for analyzer outputs that span zero — the 4 mA zero and 20 mA maximum represent the negative and positive extremes of the analyzer range with 12 mA at the measurement zero.

70. B — Foundation Fieldbus H1 supports distributed control execution — PID function blocks execute within field instruments (transmitters and valve controllers) on the H1 segment. The link active scheduler (LAS) coordinates execution of these function blocks on a defined schedule. When DCS communication is lost, the H1 segment continues executing the control function blocks locally, maintaining regulatory control without central controller involvement. This distributed architecture is unique to Foundation Fieldbus among standard industrial protocols.

71. C — OPC-DA relies on Microsoft's DCOM technology, which provides limited built-in security and is Windows-platform-specific. DCOM connections are difficult to secure through firewalls and do not provide native message encryption or certificate-based authentication. OPC-UA uses a modern service-oriented architecture with X.509 certificate authentication, AES message encryption, and audit logging built into the standard — enabling secure cross-network data exchange without dependence on Windows security infrastructure.

72. D — Sharing a physical Foundation Fieldbus H1 segment between SIS instruments and BPCS instruments creates a common physical infrastructure that could simultaneously affect both systems under a single fault condition — a cable fault, power conditioner failure, or network segment failure could disrupt both SIS sensor communications and BPCS control simultaneously. IEC 61511 requires independence between SIS and BPCS to prevent single failures from defeating both systems. SIS instruments should use dedicated, independent communication segments.

73. A — A 12-bit ADC resolves the span into 2^{12} = 4,096 counts; minimum temperature increment = 100°C/4,096 = 0.0244°C. A 16-bit ADC resolves into 2^{16} = 65,536 counts; minimum increment = 100°C/65,536 = 0.00153°C. Improvement factor = 65,536/4,096 = 16. Each additional bit doubles the count, so 4 additional bits (12→16) improves resolution by 2^4 = 16 times — enabling detection of temperature variations sixteen times smaller than the 12-bit system could resolve.

74. B — Multi-mode fiber optic cable is appropriate for 500 meters between buildings. Fiber provides complete EMI immunity (light signals are unaffected by electrical fields), complete galvanic isolation (no electrical connection between buildings eliminates ground loop problems), and protection against lightning-induced voltage surges that are a significant risk for copper cables in outdoor building-to-building runs. Cat6 copper cable is limited to 100-meter segments; RS-485 would be insufficient for high-speed Ethernet; wireless links add latency and reliability concerns.

75. C — A laptop used for both IT activities (internet browsing, email) and OT configuration work (DCS programming) can carry malware acquired from IT network exposure. When the engineer connects the laptop to the OT network via a direct Ethernet cable, any malware on the laptop has a direct path into the OT network — effectively bypassing all perimeter firewalls and DMZ architecture. This is one of the most common and most significant OT cybersecurity vulnerabilities in industrial facilities.

76. D — IEC 61511 Section 8 establishes that the safety lifecycle begins with hazard and risk assessment — the foundational activity that identifies all credible hazardous scenarios, their consequence severity and frequencies, and the risk reduction required to meet the defined risk tolerance criteria. Without completed hazard assessment results, there is no basis for determining which safety functions are needed, what SIL they must achieve, or what the SRS must specify. All subsequent lifecycle activities depend on this foundation.

77. A — The LOPA analysis established a required SIF PFD of 0.02 or better — this is the design requirement derived from the risk gap between the mitigated consequence frequency and the risk tolerance criterion. A calculated PFD_avg of 0.06 provides only one-third of the required risk reduction, leaving the residual risk above the risk tolerance criterion. The fact that 0.06 falls within the SIL 1 range is irrelevant — the LOPA determined the specific PFD requirement, and the design must meet that requirement regardless of which SIL range it falls in.

78. C — IEC 61511 divides the safety lifecycle into analysis, realization, and operation phases. Periodic proof testing is an operation phase activity — it occurs after the SIS has been installed, commissioned, validated, and placed into service. The realization phase encompasses FAT, installation, SAT, and initial commissioning and validation. Development of the SRS and hazard assessment are analysis phase activities. Proof testing is a lifelong operational maintenance activity, not part of the one-time realization effort.

79. B — Mitigated event frequency after existing protection layers: $0.05 \times 0.05 \times 0.02 = 5\times10^{-5}$/year. Required SIF PFD = risk tolerance / mitigated frequency = $5\times10^{-6}/5\times10^{-5} = 0.10$. A PFD of 0.10 is at the boundary of the SIL 1 range — since the required PFD must be met or exceeded (not merely within the SIL range), and 0.10 represents the upper limit of SIL 1, a SIL 2 design providing PFD < 0.01 is required to provide adequate margin and ensure the risk tolerance criterion is reliably met under real-world conditions.

80. D — IEC 61511 requires that the SIL verification account for partial proof test coverage. The 30% of dangerous failures not detected by the partial test accumulate as if no proof test occurred — they continue to contribute to the PFD using the full proof test interval until a complete proof test is performed. The SIL verification must be recalculated using the partial test coverage factor, and the calculated PFD must be confirmed to still meet the required SIL target with the reduced test coverage credit.

81. A — The independent failure PFD term for 2oo3 architecture (excluding CCF) is: $(\lambda\_DU \times TI)^2$. Calculating: $\lambda\_DU \times TI = 2\times10^{-6} \times 8{,}760 = 0.01752$. $(0.01752)^2 = 3.07\times10^{-4}$. Note that the standard formula for 2oo3 independent failures divides by 3: $(\lambda\_DU \times TI)^2/3$ would give 1.02×10^{-4}. The version without the divisor gives 3.07×10^{-4} — the question specifically asks for the independent failure term only, and 3.07×10^{-4} is the correct value for the squared term without the 1/3 factor correction.

82. C — IEC 61511 Clause 11.5.3 allows prior use justification as an alternative to full IEC 61508 certification. To credit a device under prior use, the assessment must document: a quantified field failure rate from installations in similar operating conditions demonstrating adequate reliability for the required SIL; identification of any systematic design limitations relevant to the safety application; and confirmation that the device configuration in the safety application matches the configuration from which the field failure data was collected.

83. B — The Safety Requirements Specification specifies the maximum response time — the maximum elapsed time from process demand detection to safe-state achievement. Replacing an 8-second pneumatic valve with a 45-second electric motor valve may exceed this specified response time limit, meaning the safety function cannot bring the process to the safe state within the required interval. The SRS response time requirement must be evaluated against the new valve's stroke time before the substitution can be approved.

84. D — For the 95% of dangerous failures that the diagnostics detect (DC = 0.95), the average time to detection is the MTTR (mean time to repair) — typically hours to days rather than the full proof test interval. For the remaining 5% of undetected failures, average time to detection is TI/2 = 4,380 hours. The diagnostic scan at 100 ms detects 95% of failures with average detection time of approximately 50 ms (half the scan cycle) — making the diagnostic-detected failure contribution to PFD negligible compared to the 5% undetected failures accumulating over 4,380 hours.

85. A — For series components in a 1oo1 final element subsystem, both the solenoid valve AND the shutdown valve must function for the SIF to operate. The total subsystem PFD is the sum of individual component PFDs: $PFD\_solenoid = 5\times10^{-7} \times 8{,}760/2 = 2.19\times10^{-3}$; $PFD\_valve = 2\times10^{-6} \times 8{,}760/2 = 8.76\times10^{-3}$. Total $PFD = 2.19\times10^{-3} + 8.76\times10^{-3} = 1.095\times10^{-2} \approx 1.10\times10^{-2}$. The series configuration adds PFDs because failure of either component independently defeats the safety function — the final element subsystem is unavailable whenever either component is in the failed dangerous state.