PRACTICE EXAM 12: 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 without square root extraction is calibrated for a maximum flow of 800 gpm at 100 in H_2O full-scale DP. The transmitter outputs 12 mA. What is the actual flow rate?

A. 400 gpm

B. 640 gpm

C. 566 gpm

D. 283 gpm

2. Using the linear Pt100 approximation $R(T) = 100(1 + 0.00385T)$, what is the indicated process temperature when the measured resistance is 123.1 Ω?

A. 60°C

B. 80°C

C. 45°C

D. 100°C

3. According to ANSI/ISA-5.1, which tag designates a level switch high-high in loop 412?

A. LAH-412

B. LAHH-412

C. LSH-412

D. LSHH-412

4. A DP level transmitter on an open vessel contains liquid at SG = 1.05 with a measurement span of 10 feet. What is the transmitter span in psi?

A. 3.47 psi

B. 4.55 psi

C. 5.60 psi

D. 6.24 psi

5. A custody transfer application measures a non-conductive liquid at cryogenic temperatures (−33°C) requiring direct mass flow measurement. Which technology is most appropriate?

A. Magnetic flowmeter with ceramic electrodes

B. Turbine flowmeter with low-temperature bearings

C. Coriolis mass flowmeter with appropriate wetted materials

D. Vortex flowmeter with a heated transmitter housing

6. A Type K thermocouple hot junction is at 500°C. The cold junction at the DCS terminal block is at 25°C. Reference table values: 500°C = 20.644 mV, 25°C = 1.000 mV (both referenced to 0°C). What net EMF does the DCS input receive before cold junction compensation?

A. 19.644 mV

B. 20.644 mV

C. 21.644 mV

D. 1.000 mV

7. A pressure transmitter has a range of 0–500 psi and an accuracy specification of ±0.2% of span. What is the maximum absolute error at any reading within the calibrated range?

A. ±0.10 psi

B. ±0.50 psi

C. ±0.20 psi

D. ±1.00 psi

8. According to ANSI/ISA-5.1, which succeeding letter in an instrument tag designates the function "Indicate"?

A. R

B. I

C. T

D. A

9. A thermowell has a tip outside diameter of 0.625 inches and is installed in a pipeline where the fluid velocity is 90 ft/s. Using a Strouhal number of 0.22, what is the vortex shedding frequency?

A. 380 Hz

B. 190 Hz

C. 760 Hz

D. 253 Hz

10. A paramagnetic oxygen analyzer installed on a nitrogen-purged process line reads 0% O_2 despite a known 5% O_2 concentration in the stream. Which condition most likely explains this zero reading?

A. Process stream oxygen has been consumed by an upstream reaction

B. Process stream pressure has exceeded the analyzer's rated pressure

C. The analyzer reference gas supply has been depleted or disconnected

D. Process stream temperature has exceeded the cell temperature rating

11. A linear variable differential transformer (LVDT) valve stem position sensor reads 0 VDC at 0% travel and 10 VDC at 100% travel. The current output is 7.5 VDC. What is the indicated stem position?

A. 62.5%

B. 50.0%

C. 85.0%

D. 75.0%

12. A calibration check shows transmitter errors of: 0% span = 0%, 25% span = +0.5%, 50% span = +1.0%, 75% span = +0.5%, 100% span = 0%. What type of calibration error is present?

A. Zero error

B. Nonlinearity error

C. Span error

D. Combined zero and span error

13. Which flow measurement technology is most appropriate for high-temperature, high-pressure saturated steam service at 400°C and 60 bar?

A. Magnetic flowmeter with high-temperature electrodes

B. Turbine flowmeter with high-temperature rated bearings

C. Vortex flowmeter with appropriate materials and electronics

D. Coriolis mass flowmeter with a large-bore straight tube

14. A Type K thermocouple is connected to the DCS using Type T extension wire. The extension wire junction is at 45°C ambient. What error results?

A. A temperature-dependent error that varies with the junction ambient temperature

B. A constant fixed offset independent of process temperature

C. No error if the cold junction compensation is correctly configured

D. Random noise proportional to the length of mismatched cable

15. A sample conditioning system cools and reduces pressure from a 280°C, 120 psig hydrocarbon gas process stream to analyzer conditions. Which sequence of operations is most appropriate?

A. Cool first to near-ambient temperature, then reduce pressure to analyzer conditions

B. Reduce pressure to below 5 psig first, then cool through a heat exchanger

C. Perform simultaneous cooling and pressure reduction through a single throttling valve

D. Reduce pressure first while maintaining temperature above the hydrocarbon dew point, then cool

16. Which level measurement technology provides simultaneous upper-surface level and liquid-liquid interface level measurements in a two-phase separator vessel?

A. Free-space radar with a 26 GHz high-frequency antenna

B. Guided-wave radar probe extending through both liquid phases

C. Ultrasonic transmitter mounted above the upper liquid surface

D. Differential pressure transmitter with external float reference

17. A DP level transmitter on an open vessel measures liquid at SG = 0.85 with a span of 4 feet between the lower and upper taps. What is the transmitter span in inches H_2O?

A. 40.8 in H_2O

B. 48.0 in H_2O

C. 34.0 in H_2O

D. 57.6 in H_2O

18. In a conductivity measurement cell, what geometric property defines the cell constant (K)?

A. Distance between the electrode faces only

B. Electrode surface area only

C. Ratio of the electrode spacing to the electrode surface area

D. Ratio of electrode surface area to electrode surface roughness

19. A glass pH electrode has a typical internal impedance of 100 MΩ to 1 GΩ. What requirement does this impose on the measurement amplifier?

A. Differential input amplification to reject common-mode interference

B. Shielded guarded cabling to prevent capacitive coupling noise

C. Temperature compensation circuit for Nernst equation slope correction

D. Input impedance greater than 10^{12} Ω to avoid loading the electrode signal

20. A magnetic flowmeter measures flow in a 4-inch Schedule 40 pipe (ID = 4.026 inches) at 200 gpm. What is the mean fluid velocity?

A. 7.3 ft/s

B. 5.0 ft/s

C. 3.2 ft/s

D. 8.6 ft/s

21. A vortex flowmeter loses measurement accuracy below its minimum Reynolds number as flow decreases. Which hardware modification most effectively extends the low-flow measurement range?

A. Installing a reduced-bore insert to increase fluid velocity through the meter at low flow

B. Adding a densitometer input for real-time density compensation

C. Replacing the flanged body with a wafer-style installation to reduce line pressure drop

D. Increasing the bluff body width to generate higher-amplitude vortices

22. Using the Pt100 linear approximation $R(T) = 100(1 + 0.00385T)$, what is the process temperature when the measured resistance is 80.31 Ω?

A. −38°C

B. −65°C

C. −51°C

D. −42°C

DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)

23. According to ANSI/ISA-5.1, which tag correctly identifies a flow recording controller with a low alarm function in loop 135?

A. FCAL-135

B. FRCAL-135

C. FRCA-135

D. FLRC-135

24. Using Ziegler-Nichols open-loop PID rules with process reaction rate R = 3.5 %/(%·min) and dead time θ = 0.5 min, what are the recommended PID settings?

A. Kc = 1.20, Ti = 1.0 min, Td = 0.25 min

B. Kc = 0.69, Ti = 2.0 min, Td = 0.50 min

C. Kc = 0.69, Ti = 0.5 min, Td = 0.25 min

D. Kc = 0.69, Ti = 1.0 min, Td = 0.25 min

25. A direct-acting flow controller has Kc = 1.8 and bias = 50%. The setpoint is 200 L/min and the current PV is 185 L/min. Using output = bias + Kc × (PV − SP), what is the current controller output?

A. 23%

B. 50%

C. 37%

D. 77%

26. An outer composition controller (τ ≈ 40 min) is being placed in cascade with an inner flow controller (τ ≈ 10 s). Before activating cascade mode, which inner loop condition is required?

A. Inner loop must be switched to manual with a fixed output value

B. Inner loop gain must be tuned to exactly match the outer loop gain

C. Inner loop must be in automatic mode accepting a remote setpoint

D. Inner loop integral time must be set equal to the outer loop integral time

27. Using Ziegler-Nichols closed-loop tuning with Ku = 8.0 and Pu = 240 s, what are the recommended PI settings?

A. Kc = 4.8, Ti = 120 s

B. Kc = 3.6, Ti = 200 s

C. Kc = 3.6, Ti = 120 s

D. Kc = 2.4, Ti = 200 s

28. In IEC 61131-3 Function Block Diagram, what output does a rising edge detector block (R_TRIG) produce?

A. A sustained HIGH while input remains TRUE

B. A pulse amplitude proportional to the input signal rise rate

C. A latched HIGH output requiring explicit reset instruction

D. A single TRUE pulse for one scan cycle at the FALSE-to-TRUE input transition

29. A feedforward model uses overall heat transfer coefficient U = 450 BTU/hr·ft²·°F. After heat exchanger fouling, actual U drops to 280 BTU/hr·ft²·°F. What effect does this model mismatch produce?

A. Control loop instability from the reversed feedforward gain

B. Systematic temperature overshoot on all feed disturbances

C. Under-correction of feed disturbances leaving residual error for feedback

D. Feedforward output saturation at maximum steam demand

30. A gap (deadband) controller has setpoint = 50% and gap = ±8%. The current level is 61%. What is the controller output behavior?

A. PID control active — error calculated against the upper gap boundary of 58%

B. No control action — level is within the configured gap region

C. Full output saturation driving level back to the 50% setpoint

D. Integral-only action accumulating proportional to time outside the gap

31. Which IEC 61131-3 programming language represents process sequences as a state-machine diagram with steps, transitions, and action associations?

A. Ladder Diagram

B. Sequential Function Chart

C. Structured Text

D. Function Block Diagram

32. Derivative-on-PV and derivative-on-error produce identical controller outputs under which specific condition?

A. When integral time equals derivative time

B. When process gain equals unity

C. When the controller is at steady state with zero accumulated error

D. When the setpoint is constant and only process disturbances drive PV changes

33. Per ISA-18.2, what alarm rate threshold defines an "alarm flood" condition during a process upset?

A. More than 10 alarms per 10-minute period

B. More than 5 alarms per 10-minute period

C. More than 20 alarms per 10-minute period

D. More than 15 alarms per 10-minute period

34. Using lambda tuning $Kc = \tau/(Kp \times (\lambda + \theta))$ with $Kp = 1.2$, $\tau = 150$ s, $\theta = 15$ s, and $\lambda = 30$ s, what is the calculated proportional gain?

A. 1.39

B. 4.17

C. 2.78

D. 3.33

35. A model predictive controller with a 25-step prediction horizon at 1-minute intervals receives a measured feed flow disturbance at $t = 0$. The model predicts composition impact in 8 minutes. When does MPC begin applying counteracting control moves?

A. At $t = 8$ minutes when the disturbance reaches the composition measurement

B. At $t = 2$ minutes — the next execution after disturbance detection

C. At $t = 10$ minutes when the disturbance enters the control horizon

D. Only after composition deviation exceeds the MPC deadband threshold

36. A direct-acting temperature controller has Kc = 3.0 and bias = 45%. A disturbance increases PV from setpoint (150°C) to 156°C. Using output = bias + Kc × (PV − SP), what is the new controller output?

A. 27%

B. 36%

C. 54%

D. 63%

37. An X-bar SPC control chart shows 15 consecutive measurements all on the same side of the centerline, all within the $\pm 3\sigma$ control limits. What Western Electric rule is violated?

A. Run rule — 8 or more consecutive points on one side indicate a process mean shift

B. No rule is violated — all points are within the control limits

C. Trend rule — 15 consecutive points confirm a directional drift

D. Range rule — 15 consecutive points indicate insufficient process variation

38. A split-range system controls reactor pressure using a nitrogen supply valve (0–50% output, opens as output increases) and a vent valve (50–100% output, opens as output increases above 50%). At 42% controller output, what is the state of each valve?

A. Nitrogen at 42% open, vent fully closed

B. Nitrogen fully open, vent at 42% open

C. Nitrogen at 84% open, vent fully closed

D. Both valves at 21% open near the crossover

39. A ratio control station maintains reagent A to wild stream B at a ratio of 0.25:1. Wild stream B flows at 2,400 L/hr. The ratio setpoint is changed to 0.30:1. What is the new reagent A setpoint?

A. 600 L/hr

B. 720 L/hr

C. 800 L/hr

D. 480 L/hr

40. Per IEC 62443, what is a "conduit" in the context of security zone architecture?

A. A physical cable pathway between two control cabinets

B. A documented organizational boundary between functional groups

C. A communication protocol change at a network interface point

D. A defined communication channel or device that transfers information between security zones

41. A loop analysis shows gain margin = 8 dB and phase margin = 35 degrees. Which assessment is correct?

A. Both margins exceed the recommended minimums — the loop has adequate stability reserves

B. Both margins are marginal and retuning is recommended

C. Gain margin is adequate; phase margin is insufficient

D. Phase margin is adequate; gain margin is excessive and loop is overtuned

42. An override control uses a high selector between a product quality controller and a temperature protection controller, both manipulating a cooling water valve. When does the temperature protection controller take over?

A. When the quality controller output exceeds 80% of range

B. When the temperature protection controller output is below the quality controller output

C. When the temperature protection controller output exceeds the quality controller output

D. When measured temperature crosses the high-temperature alarm setpoint only

43. A batch reactor temperature profile requires: ramp from 25°C to 200°C at 3°C/min, hold 90 minutes, then cool to 60°C at 2°C/min. Which IEC 61131-3 language combination best implements this profile?

A. Function Block Diagram with ramp-soak blocks chained in series

B. Sequential Function Chart for phase sequencing with Structured Text calculating ramp setpoints

C. Ladder Diagram with timer contacts switching setpoint registers at each transition

D. Structured Text using nested CASE statements to detect and execute each profile phase

44. What specific technique does "bumpless transfer" implement when switching a PID controller from manual to automatic mode?

A. All controller terms are reset to zero before automatic mode activates

B. Automatic mode activation delays until the PV error falls within 5% of setpoint

C. The integral state is initialized to match the current manual output before switching to automatic

D. Maximum output rate of change is limited for the first 10 seconds of automatic mode

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

45. A control valve sizing calculation yields Cv_required = 38. Available standard globe valve Cv ratings are: 25, 50, 80, and 130 at full open. Which valve is selected?

A. 25 — largest standard size below required Cv

B. 38 — custom trim can be ordered to exact Cv

C. 50 — the smallest standard size exceeding the required Cv

D. 80 — the next-plus-one standard size above required Cv

46. A conventional spring-loaded PRV has set pressure = 175 psig and blowdown = 6%. At what inlet pressure does the valve reseat after a relief event?

A. 164.5 psig

B. 158.0 psig

C. 170.2 psig

D. 161.0 psig

47. An autotransformer motor starter uses an 80% voltage tap. Compared to direct-on-line starting, what percentage of full-voltage starting torque is available?

A. 80%

B. 64%

C. 40%

D. 55%

48. A balanced bellows PRV design is required specifically for which installation condition?

A. High process fluid temperature above 500°F requiring special seat materials

B. Required relief flow rate exceeds the maximum capacity of available conventional valves

C. Process fluid is flammable and requires a sealed bonnet design

D. Variable superimposed back pressure exceeds 10% of set pressure

49. A control valve liquid sizing calculation requires: $Q = 320$ gpm, $SG = 0.92$, $\Delta P = 25$ psi. Using $Cv = Q \times \sqrt{(SG/\Delta P)}$, what is the required Cv?

A. 41.2

B. 52.8

C. 61.4

D. 74.6

50. A fail-closed ESD valve uses an air-to-open spring-return actuator controlled by a 3-way solenoid valve. During an ESD trip event (solenoid de-energizes), which solenoid connection is established?

A. Actuator port connected to exhaust, venting pneumatic supply to atmosphere

B. Supply port connected to actuator, maintaining opening air pressure

C. All ports blocked, holding actuator at last position

D. Supply connected to exhaust, bypassing actuator entirely

51. A control valve body material must be selected for liquid ammonia service at −33°C. Which material is correct?

A. Carbon steel (ASTM A216 WCB) rated for −29°C with impact testing

B. Austenitic stainless steel (Type 304 or 316) suitable for cryogenic service

C. Cast iron — lowest thermal expansion coefficient at cryogenic temperatures

D. Chrome-molybdenum alloy steel (1.25Cr-0.5Mo) — standard low-temperature grade

52. Per API 520, a rupture disc is installed immediately upstream of a spring-loaded PRV as a combination device. What correction factor is applied to the PRV's certified discharge coefficient?

A. Kc = 1.10 — combination increases effective discharge capacity

B. Kc = 0.85 — conservative reduction for system uncertainty

C. Kc = 1.00 — no correction required for an upstream disc

D. Kc = 0.90 — API 520 combination device correction factor

53. A centrifugal pump operates at rated speed consuming 90 kW. A VSD reduces pump speed to 70% of rated. Using the affinity law for power, what is the new shaft power?

A. 30.9 kW

B. 44.1 kW

C. 63.0 kW

D. 22.1 kW

54. A valve positioner calibration check shows: 4 mA = 0% travel, 12 mA = 53% travel, 20 mA = 100% travel. What type of calibration error is present?

A. Zero error — the zero point is incorrectly set

B. Span error — total travel range is compressed below specified stroke

C. Linearity error — mid-range deviates from the straight line between correct endpoints

D. Combined zero and span error requiring both adjustments

55. A globe valve body material is required for 98% concentrated sulfuric acid service at 120°C. Which material is most appropriate?

A. Type 316 stainless steel — adequate for dilute H_2SO_4 below 65°C

B. Cast iron — concentrated H_2SO_4 above 70% forms a protective sulfate passivation layer

C. Alloy 20 (N08020) — optimized for dilute to moderate acid concentrations

D. Monel 400 — appropriate for alkaline environments and mild organic acids

56. A gate valve in slurry service shows severe erosion on the gate and seat surfaces after 6 months of service. Which modification best extends trim life?

A. Increasing gate closure force through a higher-thrust actuator

B. Switching from a parallel-gate to a wedge-gate design

C. Installing a downstream pipe reducer to control slurry velocity

D. Hard-facing the gate and seat contact surfaces with tungsten carbide

57. A spring-loaded PRV is set at 250 psig on a pressure vessel with MAWP = 275 psig. Per ASME Section VIII, is this configuration compliant?

A. Yes — set pressure (250 psig) does not exceed the vessel MAWP (275 psig)

B. No — PRV set pressure must equal the vessel MAWP exactly

C. No — PRV set pressure must be at least 10% below MAWP

D. Yes — compliance requires only that the set pressure not exceed the design pressure

58. A solenoid valve is rated "normally de-energized, energize to open." During an ESD demand, the SIS de-energizes the solenoid. What position does the connected actuator-driven valve assume?

A. Opens — the de-energized spring drives the valve open

B. Freezes at its current position when the solenoid de-energizes

C. Closes — de-energization returns the solenoid to its normal closed position

D. Oscillates between positions as pneumatic pressure and spring force equalize

59. Which check valve design provides the fastest closure to minimize water hammer in a large, high-velocity pump discharge system?

A. Full-swing check valve relying on gravity for disc closure

B. Dual-plate wafer check valve with spring-loaded half-discs closing at only 35–45° travel

C. Ball check valve returning to seat under gravity alone

D. Piston lift check valve with hydraulic dashpot controlling closure speed

60. A 3-inch equal percentage globe valve has $Cv_{max} = 120$ and rangeability = 50:1. Using $Cv = Cv_{min} \times R^x$, what is the approximate Cv at 40% travel?

A. 48.0 (40% of Cv_{max})

B. 24.0 (linear approximation at 40%)

C. 12.0 (midpoint between minimum and 50% Cv)

D. 11.5 (equal percentage exponential calculation at 40% travel)

61. A control valve requiring ANSI/FCI Class VI (bubble-tight) shutoff must use which seat design?

A. Lapped metal-to-metal seat and plug with tight dimensional tolerances

B. Hard-faced Stellite seat and plug with precision grinding

C. Soft seat using elastomeric or PTFE insert providing zero-leakage sealing

D. Hardened stainless steel seat with chrome-plated plug face

62. A motor MCC thermal overload relay is set at 115% of motor FLA. The motor FLA is 75 A. At what current does the overload relay operate?

A. 86.3 A

B. 75.0 A

C. 93.8 A

D. 67.5 A

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

63. A 4–20 mA loop has: DCS supply = 24 VDC, input resistor = 250 Ω, IS Zener barrier = 90 Ω, and cable loop resistance = 160 Ω. What is the transmitter terminal voltage at 20 mA?

A. 10.0 VDC

B. 14.0 VDC

C. 16.0 VDC

D. 12.0 VDC

64. A PROFIBUS DP network at 1.5 Mbit/s (maximum segment length 200 m) must reach a remote panel 280 meters from the master. What is the correct solution?

A. Reduce baud rate to 187.5 kbit/s to extend the segment length to 1,000 m

B. Install additional termination resistors at the 200-meter mark

C. Replace PROFIBUS DP with PROFIBUS PA for this extended segment

D. Install a PROFIBUS DP repeater before the 200-meter segment limit

65. An intrinsic safety circuit has cable capacitance of 120 nF and cable inductance of 1.5 mH. The IS barrier entity parameters are Ca = 150 nF and La = 3 mH. Is the cable IS-compliant?

A. Non-compliant — capacitance exceeds 80% of Ca requiring derating

B. Non-compliant — inductance must be below 1.0 mH for Zone 1 service

C. Compliant — cable capacitance and inductance are both within entity parameter limits

D. Compliant — only voltage and current parameters require entity verification

66. In HART point-to-point mode (address 0), what is the status of the 4–20 mA analog signal during HART digital communication?

A. The 4–20 mA analog signal continues uninterrupted while HART FSK data is superimposed

B. The 4–20 mA signal is suspended briefly during each HART communication burst

C. The 4–20 mA signal holds at its last value during active digital communication

D. The 4–20 mA signal shifts to a fixed 12 mA during HART handshaking

67. For NEC Class I, Zone 0 classified areas (continuously hazardous atmospheres), which protection technique is specifically rated for this classification?

A. Explosion-proof enclosure (Ex d)

B. Increased safety (Ex e) with appropriate IP rating

C. Non-incendive (Ex nA) — no arcing under normal operation

D. Intrinsic safety (Ex ia) — the only protection technique rated for Zone 0

68. A WirelessHART transmitter achieves 97% packet delivery success to the gateway. What is the primary WirelessHART mechanism responsible for maintaining this high reliability?

A. Mesh routing through multiple intermediate relay devices

B. Time-synchronized channel hopping across 15 frequency channels in the 2.4 GHz band

C. Adaptive power control increasing transmit strength when delivery drops below threshold

D. Frequency diversity using an automatic 900 MHz backup when the 2.4 GHz band is congested

69. Per NAMUR NE 43 signal conventions, what current range defines the valid process measurement signal?

A. 0 to 24 mA including all fault and measurement states

B. 3.8 to 20.5 mA including warning bands on both sides

C. 4 to 20 mA — the valid process measurement range within the broader fault detection framework

D. 3.6 to 21.0 mA combining the measurement and all fault detection bands

70. An EtherNet/IP network uses Device Level Ring (DLR) topology. A single cable fault occurs between two ring nodes. What is the expected network behavior?

A. DLR detects the fault in milliseconds and reroutes traffic through the surviving ring path

B. All nodes downstream of the break in the ring direction lose communication until repaired

C. Spanning Tree Protocol reconverges the network topology in 15–30 seconds

D. DLR transfers all devices to a star topology through the designated DLR supervisor

71. A data diode is installed between the OT DCS historian and the corporate IT network. What specific capability does hardware data diode enforcement provide?

A. Deep packet inspection filtering malicious commands before they reach the OT network

B. Encrypted data transit preventing man-in-the-middle attacks on historian data

C. User authentication before IT personnel can access historian data

D. Physical hardware enforcement of one-way OT-to-IT data flow — IT commands cannot reach OT systems

72. A DCS analog output card provides 16-bit DAC resolution generating a 4–20 mA valve position signal. A cost-reduction proposal replaces it with a 12-bit DAC. By what factor does valve position resolution degrade?

A. 4× coarser — 4-bit difference applied linearly

B. 16× coarser — $2^{16}/2^{12}$ = 16× resolution reduction

C. 8× coarser — factor based on half-bit rounding adjustment

D. 2× coarser — resolution halves for each pair of bits removed

73. An OPC-UA server on a DCS historian uses an expired X.509 certificate. An MES client attempts to connect. What occurs?

A. The connection proceeds with reduced encryption key length

B. The connection falls back to unencrypted OPC-DA legacy mode

C. The MES client rejects the server identity verification and blocks the connection

D. The certificate expiry is silently logged and the connection proceeds normally

74. A DCS workstation security audit finds that routine operations run under Windows Administrator-level privileges. What is the primary security concern?

A. Malware executing in that session inherits full Administrator rights across the system and network

B. Administrator processes consume excess CPU resources degrading DCS application performance

C. DCS vendor support contracts may be voided by non-standard privilege configurations

D. Audit logging is incomplete for Administrator-level sessions in some Windows versions

75. An OT cybersecurity policy requires all vendor remote access sessions to be time-limited, logged, and restricted by source IP address. Which single technical control enforces all three requirements simultaneously?

A. The process historian server managing session timeouts through database connection limits

B. The DCS engineering workstation antivirus monitoring and terminating active sessions

C. The corporate IT perimeter firewall with time-based IP access control rules

D. A dedicated remote access gateway in the OT DMZ enforcing time limits, session logging, and IP source filtering

DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)

76. A 2oo3 SIS sensor configuration has $\beta = 0.10$, $\lambda\_DU = 4\times10^{-6}$/hr per transmitter, and TI = 8,760 hr. What is the common cause failure (CCF) contribution to PFD_avg?

A. 8.76×10^{-4}

B. 1.75×10^{-3}

C. 3.50×10^{-3}

D. 4.38×10^{-4}

77. Per IEC 61511, the Safety Requirements Specification must be completed before which lifecycle activity?

A. The process hazard and risk assessment identifying hazardous scenarios

B. The LOPA calculation determining the required SIL for each SIF

C. The detailed SIS hardware and software design phase

D. The procurement and delivery of SIS field instruments

78. Per IEC 61511, which document formally specifies the functional and integrity requirements for each safety instrumented function before design begins?

A. Safety Requirements Specification (SRS)

B. SIL Verification Calculation report

C. Functional Safety Assessment report

D. Process Hazard Analysis worksheet

79. A LOPA analysis for a compressor surge scenario yields: initiating event = 0.3/year, BPCS antisurge controller PFD = 0.1, independent mechanical trip PFD = 0.05. Risk tolerance = 5×10^{-5}/year. What is the required SIF PFD?

A. 0.10 — SIL 1 upper boundary

B. 0.001 — SIL 3 required

C. 0.01 — SIL 2 lower boundary

D. 0.033 — SIL 1 required

80. A SIF proof test is documented as passed because the sensor and logic solver functioned correctly. The ESD valve was not tested for stroke completion within the SRS-specified response time. Which IEC 61511 requirement was not satisfied?

A. The pre-startup functional safety assessment requirement

B. The periodic proof test requirement to verify the complete cause-to-effect path including final element response

C. The SIL verification requirement confirming the achieved PFD

D. The SRS update requirement following proof test completion

81. A 1oo2 SIS sensor configuration has each transmitter with $\lambda\_DU = 2\times10^{-6}$/hr and TI = 4,380 hr. Ignoring CCF, what is the independent failure PFD contribution using $(\lambda\_DU \times TI)^2/3$?

A. 3.83×10^{-5}

B. 7.66×10^{-5}

C. 2.56×10^{-5}

D. 1.28×10^{-4}

82. IEC 61511 Edition 2 requires cybersecurity to be addressed within the SIS safety lifecycle. What specific cybersecurity element is required in the Safety Requirements Specification?

A. Identification of cybersecurity threats to the SIS and documentation of countermeasures in the SRS

B. Annual third-party penetration testing of all SIS network segments

C. Encryption of all fieldbus communications between SIS components

D. Physical isolation of all SIS hardware from any network-connected equipment

83. A SIS component has a manufacturer-specified useful life of 15 years. The plant is approaching year 14 of operation without replacement. Per IEC 61511, what action is required before the useful life expires?

A. Document component condition and defer replacement if no failures are observed

B. Reduce the proof test interval by 50% as compensation for the approaching end of useful life

C. Request manufacturer extension of the useful life certification period

D. Replace before the useful life expires or revalidate the SIL verification using appropriate beyond-useful-life failure data

84. Per IEC 61511, what is the requirement regarding sensor independence between the SIS and the BPCS?

A. Sensors may be shared if the BPCS input is read-only and cannot influence the SIS measurement

B. Separate independent sensors are required — shared sensors represent a single point of failure that could simultaneously defeat both protection and control

C. Sensors may be shared if they have dual isolated output channels on separate wiring pairs

D. Shared sensors are acceptable for SIL 1 functions but not for SIL 2 or higher

85. A SIF is classified as high-demand mode with a demand rate of 5 per year requiring SIL 2. Per IEC 61511, which performance metric and target apply?

A. PFD_avg — SIL 2 requires $0.001 \leq PFD < 0.01$ regardless of demand rate

B. MTBF — mean time between failures must exceed 2 years for SIL 2 classification

C. PFH — probability of dangerous failure per hour; SIL 2 requires $10^{-7} \leq PFH < 10^{-6}$ /hr

D. RRF — risk reduction factor of 100 to 1,000 applicable for high-demand classification

PRACTICE EXAM 12: ANSWER KEY AND EXPLANATIONS

1. C — Without square root extraction, at 12 mA (50% of span), DP = 50 in H_2O. Flow = 800 × √(50/100) = 800 × 0.707 = 566 gpm. Disabling extraction requires the DCS to apply it externally — failing to do so produces this characteristic underestimate of actual flow.
2. A — Solving for T: 123.1 = 100(1 + 0.00385T) → 0.231 = 0.00385T → T = 60°C. The Pt100 linear approximation is adequate for most exam calculations across the −200°C to +850°C operating range.
3. D — Per ANSI/ISA-5.1: L = Level, S = Switch, H = High, H = High (second level). LSHH designates a Level Switch High-High — a discrete device that changes state when level reaches the second-tier high threshold, typically initiating automatic protective action.
4. B — Span in psi = SG × h × 62.4/144 = 1.05 × 10 × 62.4/144 = 655.2/144 = 4.55 psi. The SG correction accounts for the denser fluid generating more hydrostatic pressure per foot than the water-reference conversion factor assumes.
5. C — Coriolis meters measure mass flow directly through the Coriolis force on a vibrating tube, completely independent of fluid conductivity, viscosity, or composition. Non-conductive fluids eliminate magnetic flowmeters, and cryogenic conditions require appropriate wetted material selection.
6. A — Net EMF at the DCS terminals = hot junction EMF − cold junction EMF = 20.644 − 1.000 = 19.644 mV. Cold junction compensation adds the 1.000 mV correction to recover the full 20.644 mV equivalent representing 500°C above the 0°C reference.
7. D — Span-based accuracy: ±0.2% × 500 psi = ±1.00 psi absolute error at any reading within the calibrated range. At low readings this represents a large percentage error — demonstrating why span-referenced specs are less favorable than reading-based specs for low-end measurements.
8. B — Per ANSI/ISA-5.1, "I" as a succeeding letter designates Indicating — a device that provides local or remote visual display of the measured value. "R" = Recording, "T" = Transmitter, "A" = Alarm.
9. A — f_w = St × V/d. Converting tip diameter: 0.625/12 = 0.05208 ft. f_w = 0.22 × 90/0.05208 = 19.8/0.05208 = 380.2 ≈ 380 Hz. This frequency must satisfy the ASME PTC 19.3 TW criterion r < 0.80 relative to the thermowell natural frequency.
10. C — Paramagnetic oxygen analyzers establish measurement by comparing the sample gas to a reference gas stream. Without a reference gas supply, the instrument cannot form the differential

comparison that constitutes the measurement — producing a spurious zero output despite actual oxygen concentration in the sample.

11. D — Linear LVDT scaling: position = (7.5 VDC / 10.0 VDC) × 100% = 75%. The LVDT output varies linearly from 0 VDC at 0% travel to 10 VDC at 100% travel — direct proportional calculation applies.
12. B — The error is 0 at both endpoints (0% and 100% span) but peaks at +1.0% at midrange (50% span), tapering symmetrically between. This humped, S-shaped error pattern with correct endpoints is the defining signature of a nonlinearity error — not correctable by zero or span adjustment alone.
13. C — Vortex flowmeters have no rotating parts to wear in high-temperature steam service, withstand 400°C and 60 bar with appropriate materials, and measure both mass and volumetric flow when paired with density compensation. Coriolis meters at this size and condition would be prohibitively expensive and pressure-drop-intensive.
14. A — Type K and Type T extension wires have different Seebeck coefficients. At the mismatched junction at 45°C ambient, a spurious EMF proportional to that ambient temperature is generated — producing a temperature-dependent error that changes as the junction's ambient temperature changes.
15. D — For hot high-pressure hydrocarbon gas, pressure must be reduced first while maintaining temperature above the hydrocarbon dew point throughout. Cooling before pressure reduction allows heavy components to condense at high pressure where dew points are elevated, permanently removing them from the sample stream before analysis.
16. B — Guided-wave radar detects microwave reflections at each dielectric discontinuity along the probe — at the upper liquid surface and at the liquid-liquid interface. This allows simultaneous upper level and interface level measurements from a single instrument, a capability free-space radar and ultrasonic sensors cannot provide.
17. A — Span in in H_2O = SG × h × 12 in/ft = 0.85 × 4 × 12 = 40.8 in H_2O. The SG multiplier scales the span below the 48 in H_2O that a pure water column of equal height would produce.
18. C — Cell constant K = electrode spacing (L) / electrode surface area (A). This geometric ratio converts the measured conductance (in Siemens) to actual solution conductivity (in S/cm). Cells with different geometries produce different cell constants requiring individual calibration.
19. D — A glass pH electrode with 100 MΩ to 1 GΩ internal impedance requires a measurement amplifier with input impedance exceeding 10^{12} Ω. If amplifier input impedance approaches electrode impedance, significant current flows through the electrode, disturbing the equilibrium potential and producing large measurement errors.
20. B — Convert: 200 gpm × 0.002228 = 0.4456 ft^3/s. Pipe area: D = 4.026/12 = 0.3355 ft; A = $\pi(0.3355)^2/4$ = 0.08840 ft^2. V = 0.4456/0.08840 = 5.04 ≈ 5.0 ft/s. SG does not affect velocity — only volumetric flow and pipe area determine mean velocity.

21. A — A reduced-bore insert creates a narrower flow passage, increasing fluid velocity at the same volumetric flow rate. Higher velocity raises the Reynolds number above the vortex meter's minimum threshold, extending the low-flow measurement range without changing the full-scale calibration.

22. C — R = 80.31 Ω. Solving: $80.31 = 100(1 + 0.00385T) \rightarrow 0.8031 = 1 + 0.00385T \rightarrow 0.00385T = -0.1969 \rightarrow T = -51.1°C \approx -51°C$. Resistance below 100 Ω always indicates a sub-zero process temperature for Pt100 sensors.

23. B — Per ANSI/ISA-5.1: F = Flow, R = Record, C = Controller, A = Alarm, L = Low. FRCAL-135 correctly assembles these function letters in tag order — flow recording controller with a low alarm function on loop 135.

24. D — Z-N open-loop PID using reaction rate notation: $Kc = 1.2/(R \times \theta) = 1.2/(3.5 \times 0.5) = 1.2/1.75 = 0.686 \approx 0.69$. $Ti = 2\theta = 1.0$ min. $Td = 0.5\theta = 0.25$ min. These settings target the quarter-decay ratio response criterion.

25. A — For direct-acting controller: output = bias + Kc × (PV − SP) = 50 + 1.8 × (185 − 200) = 50 + 1.8 × (−15) = 50 − 27 = 23%. The negative error drives output well below bias, appropriate for a direct-acting controller on a process where low PV requires low output.

26. C — For cascade control, the inner loop must be in automatic mode with remote setpoint enabled — its setpoint input comes from the outer controller's output. If the inner loop is in manual, it ignores the cascade setpoint and cascade provides no benefit regardless of outer loop action.

27. B — Z-N closed-loop PI: Kc = 0.45 × Ku = 0.45 × 8.0 = 3.6. Ti = Pu/1.2 = 240/1.2 = 200 s. The 0.45 multiplier and Pu/1.2 integral time are the standard Z-N PI formulas — distinct from PID (0.6×Ku, Pu/2, Pu/8) which adds derivative action.

28. D — The R_TRIG (rising edge trigger) function block in IEC 61131-3 detects the FALSE-to-TRUE transition of its input and produces a single TRUE output for exactly one scan cycle. This one-shot behavior is essential for triggering discrete events on signal rising edges without continuous activation throughout the TRUE state.

29. C — With actual U = 280 versus model U = 450, the feedforward calculates steam based on the higher thermal performance that no longer exists — the predicted correction is only 62% of what the process actually requires. The residual 38% correction must come from the feedback controller after a temperature deviation develops.

30. A — Gap control activates when the PV moves outside the deadband (50% ± 8% = 42% to 58%). At 61%, the level has exited the upper gap boundary at 58%, so the controller activates PID action with error calculated against the 58% boundary, not the 50% setpoint.

31. B — Sequential Function Chart (SFC) represents process sequences graphically as a state-machine diagram with step boxes, transition bars connecting steps, and action blocks associated with each step. This graphical structure is designed specifically for sequential process control and batch automation.

32. D — When setpoint is constant, $d(SP)/dt = 0$, making $d(error)/dt = d(SP - PV)/dt = -d(PV)/dt$. The derivative of error equals the negative of the derivative of PV — both implementations produce mathematically identical outputs only during constant-setpoint disturbance conditions.

33. A — ISA-18.2 defines an alarm flood as exceeding 10 alarms per 10-minute period — the threshold above which operators cannot effectively assess, prioritize, and respond to all active alarms. This benchmark drives alarm rationalization and state-based alarming design requirements.

34. C — $Kc = \tau/(Kp \times (\lambda + \theta)) = 150/(1.2 \times (30 + 15)) = 150/(1.2 \times 45) = 150/54 = 2.78$. Setting $\lambda = 2\theta$ produces moderately aggressive tuning — the closed-loop time constant equals twice the dead time, balancing response speed with robustness.

35. B — MPC's process model allows it to predict disturbance impact across its entire prediction horizon. At the next execution (t = 2 minutes for a 2-minute execution interval), MPC calculates that the current disturbance will affect composition in 8 minutes and applies counteracting moves immediately — no waiting for measured composition deviation.

36. D — Output = bias + Kc × (PV − SP) = 45 + 3.0 × (156 − 150) = 45 + 18 = 63%. Direct-acting increases output when PV rises above setpoint — this 63% output reflects the controller driving the cooling or venting valve open to reject the temperature disturbance.

37. A — The Western Electric Run Rule flags 8 or more consecutive points on the same side of the centerline as a special cause, regardless of whether points are within the $\pm 3\sigma$ limits. Fifteen consecutive one-sided points strongly violates this rule, indicating the process mean has shifted and requires investigation.

38. C — Nitrogen supply valve range: 0–50% output, fully closed at 0%, fully open at 50%. At 42% output: position = (42/50) × 100 = 84% open. Vent valve range: 50–100% output, fully closed at 50%. At 42% output, the vent valve is fully closed since 42% is below its 50% activation threshold.

39. B — New reagent A setpoint = ratio × wild stream = 0.30 × 2,400 = 720 L/hr. The ratio station multiplies the wild stream measurement by the configured ratio factor to generate the controlled stream setpoint.

40. D — Per IEC 62443, a conduit is a defined communication channel, path, or mechanism that transfers information between security zones. This includes network links, protocols, wireless paths, and intermediary devices — any defined pathway crossing a zone boundary requires security assessment.

41. A — Industry-recommended stability margins are gain margin ≥ 6 dB and phase margin ≥ 30°. With GM = 8 dB (exceeds 6 dB) and PM = 35° (exceeds 30°), both margins satisfy their minimums — the loop has adequate stability reserve for normal process parameter variations.

42. C — A high selector passes the larger of two controller outputs to the final element. When the temperature protection controller demands a larger output (more cooling water flow) than the quality

controller, the high selector correctly passes this larger protective demand, overriding normal quality control to prevent equipment damage.

43. B — Sequential Function Chart naturally represents the multi-phase batch sequence (ramp, hold, cool) as a state machine with each phase as a distinct step and timer-based or temperature-based transitions between steps. Structured Text within each step action provides the mathematical calculation of the linearly ramped setpoint value in real time.

44. C — Bumpless transfer initializes the PID controller's integral state to match the current manual output before enabling automatic mode. At the transfer moment, calculated output equals manual output — the controller then adjusts smoothly from this point as error develops, producing zero output discontinuity.

45. C — Control valve sizing always requires the next larger standard Cv rating above the calculated requirement. The Cv = 25 is undersized; the Cv = 50 is the smallest standard rating that provides adequate flow capacity for the required Cv = 38.

46. A — Blowdown = 6% × 175 psig = 10.5 psi. Reseat pressure = 175 − 10.5 = 164.5 psig. Blowdown provides hysteresis preventing repeated opening and closing (chattering) immediately after the relief event.

47. B — Autotransformer at 80% voltage tap: starting torque varies with voltage squared = $(0.80)^2 = 0.64$ = 64% of full-voltage starting torque. Both torque and line-side current reduce by the square of the voltage ratio through the transformer action.

48. D — Variable or high superimposed back pressure above 10% of set pressure variably shifts a conventional valve's effective opening pressure because back pressure acts in the same direction as the closing spring. A balanced bellows isolates the spring chamber from back pressure, maintaining consistent set pressure regardless of downstream conditions.

49. C — $Cv = Q \times \sqrt{SG/\Delta P} = 320 \times \sqrt{0.92/25} = 320 \times \sqrt{0.0368} = 320 \times 0.1918 = 61.4$. The SG correction is necessary because the fluid is lighter than the water reference used in the standard Cv equation.

50. A — De-energizing the 3-way solenoid connects the actuator air port to the exhaust port, venting pneumatic pressure to atmosphere. With air pressure removed, the return spring drives the valve to its fail-closed position — the intended safe state for an ESD trip event.

51. B — Liquid ammonia at −33°C is at its atmospheric boiling point, requiring cryogenic-grade materials. Austenitic stainless steel (Type 304 or 316) maintains adequate ductility and impact toughness at this temperature and is compatible with ammonia service. Carbon steel approaches its ductile-to-brittle transition at these temperatures.

52. D — Per API 520, installing a rupture disc upstream of a PRV requires applying the combination correction factor Kc = 0.90 to the PRV's certified discharge coefficient. This 10% capacity reduction accounts for flow disturbance introduced by the ruptured disc material remaining in the flow path.

53. A — Affinity law for power: $P \propto N^3$. P_new = 90 × $(0.70)^3$ = 90 × 0.343 = 30.87 ≈ 30.9 kW. The cubic relationship makes speed reduction highly effective for energy savings — a 30% speed reduction cuts power consumption by nearly 66%.

54. C — Zero calibration at 4 mA (0% travel) is correct; span calibration at 20 mA (100% travel) is correct. The 3% deviation at 12 mA (53% actual vs. 50% expected) with both endpoints correct indicates a linearity error in the mechanical cam or electronic characterizer — not correctable by simple zero or span adjustment.

55. B — Concentrated sulfuric acid above approximately 70% concentration passivates cast iron through formation of a ferrous sulfate surface layer, making it the traditional material for concentrated H_2SO_4 service. Type 316 SS fails rapidly in concentrated H_2SO_4; Alloy 20 and Monel are suited for other acid/alkaline services respectively.

56. D — Hard-facing gate and seat surfaces with tungsten carbide (approximately 1,800 HV hardness) dramatically extends service life by resisting abrasive wear from slurry particles. The hardness of tungsten carbide far exceeds most slurry abrasives, converting months of service life to years.

57. A — ASME Section VIII UG-134 requires PRV set pressure not to exceed the vessel MAWP. A 250 psig set pressure on a 275 psig MAWP vessel satisfies this requirement — the PRV opens before the vessel reaches its maximum allowable pressure, providing the intended protection.

58. C — "Normally de-energized, energize to open" means the solenoid's un-powered (normal) state holds the output in the closed position. When the ESD trip de-energizes the solenoid, it returns to its normal closed state — venting the actuator and allowing the spring to close the process valve to its safe state.

59. B — Dual-plate wafer check valves close in only 35–45° of disc travel versus 90° for full-swing designs. The shorter closure travel takes significantly less time, enabling the valve to close before significant reverse flow velocity develops — minimizing the momentum of reversing fluid and the resulting water hammer pressure spike.

60. D — Cv_min = 120/50 = 2.4. At 40% travel: Cv = 2.4 × 50^0.40. log(50) = 1.699; 0.40 × 1.699 = 0.6796; 10^0.6796 = 4.783. Cv = 2.4 × 4.783 = 11.5. Equal percentage trim produces only about 9.6% of maximum Cv at 40% travel — far less than linear trim would produce at the same position.

61. C — ANSI/FCI Class VI (bubble-tight) shutoff is achievable only with soft seat materials — elastomers (PTFE, Buna-N) that elastically deform to create zero-leakage contact with the plug. Metal-to-metal seats cannot reliably achieve Class VI regardless of dimensional precision because microscopic surface imperfections always allow some leakage.

62. A — Trip current = 1.15 × 75 A = 86.25 ≈ 86.3 A. Thermal overload relays are set above FLA to allow brief overloads during starting while protecting motor windings from sustained overcurrent heating that degrades insulation life.

63. B — Total series resistance = 250 + 90 + 160 = 500 Ω. Voltage drop at 20 mA = 0.020 × 500 = 10.0 V. Transmitter terminal voltage = 24.0 − 10.0 = 14.0 VDC. This exceeds most transmitter minimum terminal voltage requirements with adequate compliance margin.

64. D — At 1.5 Mbit/s, PROFIBUS DP maximum segment length is 200 meters. Installing a repeater before this limit regenerates the signal at full amplitude and timing quality, beginning a new 200-meter segment that can reach the 280-meter device within the new segment's distance budget.

65. C — IS cable compliance requires cable capacitance ≤ Ca AND cable inductance ≤ La. Cable capacitance (120 nF) ≤ Ca (150 nF) ✓ and cable inductance (1.5 mH) ≤ La (3 mH) ✓ — both entity parameters are satisfied, confirming IS compliance for the cable installation.

66. A — HART FSK digital communication superimposes a low-amplitude AC signal (1200/2200 Hz) on the existing 4–20 mA DC loop current. The DC component is unaffected — both signals coexist simultaneously on the same two wires, enabling digital communication without interrupting the primary analog measurement.

67. D — Intrinsic safety (Ex ia) is the only IEC protection technique rated for Zone 0 (continuously hazardous atmosphere). It limits electrical energy below the minimum ignition energy under both normal operation and any single component fault — the only technique providing fault-tolerant protection for continuous hazard presence.

68. B — WirelessHART uses time-synchronized channel hopping across 15 frequency channels in the 2.4 GHz ISM band. When narrowband interference disrupts a specific channel, the next scheduled transmission automatically uses a different channel, providing statistical diversity that maintains high packet delivery rates.

69. C — Per NAMUR NE 43, 4–20 mA is the valid process measurement signal range. The standard extends detection capability to below 3.6 mA (open circuit/failure) and above 21.0 mA (overrange/failure), but the process measurement itself occupies the 4–20 mA range.

70. A — DLR (Device Level Ring) protocol continuously monitors the ring topology and detects cable faults in less than 3 milliseconds. Upon fault detection, it reconfigures traffic to traverse the ring in the opposite direction through the surviving path — maintaining uninterrupted communication for all nodes.

71. D — A data diode uses physical hardware (typically a fiber optic transmitter with no return receiver) to enforce absolute one-way communication. IT systems physically cannot transmit commands to OT systems through the diode — hardware enforcement that cannot be bypassed by software misconfiguration, unlike software-based firewalls.

72. B — A 16-bit DAC produces 2^{16} = 65,536 steps; a 12-bit DAC produces 2^{12} = 4,096 steps. Resolution ratio = 65,536/4,096 = 16×. Each removed bit halves resolution — removing 4 bits (16 → 12) degrades resolution by 2^4 = 16 times.

73. C — OPC-UA uses X.509 certificates for mutual authentication between server and client. An expired certificate means the server cannot prove its current identity to the connecting MES client — the client correctly rejects the connection to prevent communicating with an unverified or potentially spoofed server.

74. A — Processes running under Administrator privileges on a DCS workstation grant any malware that infects that session full system rights and elevated network access. This enables immediate privilege escalation, persistent installation, lateral movement across the OT network, and potential access to safety-critical control functions.

75. D — A dedicated remote access gateway in the OT DMZ is the single technical control that simultaneously enforces session time limits (automatic disconnect), logs all session activity (keystrokes, commands, screen capture), and applies source IP address and destination port filtering for all incoming connections.

76. B — CCF term = $\beta \times \lambda\_DU \times TI/2 = 0.10 \times 4{\times}10^{-6} \times 8{,}760/2 = 0.10 \times 0.01752 = 1.752{\times}10^{-3} \approx 1.75{\times}10^{-3}$. The CCF term typically dominates the total 2oo3 PFD in annual proof test configurations — reinforcing why diversity is critical in redundant safety sensor architectures.

77. C — Per IEC 61511 Clause 10, the Safety Requirements Specification must be completed before detailed SIS hardware and software design begins. The SRS defines what the SIS must accomplish — it is the baseline against which the completed design is formally verified.

78. A — The Safety Requirements Specification per IEC 61511 formally documents all functional and integrity requirements for each SIF before design work begins — safe states, demand descriptions, SIL targets, response times, and input/output specifications. It is the foundational lifecycle document against which the SIS design is verified.

79. D — Mitigated frequency = 0.3 × 0.1 × 0.05 = $1.5{\times}10^{-3}$/year. Required SIF PFD = $5{\times}10^{-5}/1.5{\times}10^{-3}$ = 0.0333 ≈ 0.033. A PFD of 0.033 falls within the SIL 1 range (0.01–0.1), confirming SIL 1 is required with a specific numerical target of 0.033.

80. B — IEC 61511 requires proof tests to verify the complete cause-to-effect path — from sensor activation through logic solver response to final element achieving its specified safe position within the SRS-defined response time. Testing only the sensor and logic solver satisfies only part of this requirement.

81. C — Independent PFD for 1oo2 = $(\lambda\_DU \times TI)^2/3 = (2{\times}10^{-6} \times 4{,}380)^2/3 = (0.00876)^2/3 = 7.674{\times}10^{-5}/3 = 2.56{\times}10^{-5}$. The 1/3 factor corrects for the specific combinatorial probability of exactly two independent simultaneous failures in a 1oo2 architecture.

82. A — IEC 61511 Edition 2 Clause 8.2.4 explicitly requires cybersecurity threats to the SIS to be identified and countermeasures documented within the SRS, integrating cybersecurity requirements directly into the functional safety lifecycle. Annual penetration testing, encryption mandates, and physical isolation are not blanket requirements.

83. D — IEC 61511 requires SIS components to be replaced before their useful life expires, or the SIL verification must be revalidated using failure rate data appropriate for the wear-out region where the constant-region failure rate assumption is no longer valid. The bathtub curve's wear-out phase produces higher actual failure rates than the original qualification data reflects.

84. B — IEC 61511 Clause 9.5 requires separate independent sensors for SIS and BPCS. Shared sensors create a single point of failure — one sensor failure simultaneously removes the process variable from both the control and safety systems. No isolation technique compensates for this fundamental single-point-of-failure vulnerability.

85. C — IEC 61511 specifies PFH (probability of dangerous failure per hour) for high-demand mode SIFs where demand rate exceeds once per year. For SIL 2 high-demand mode, IEC 61511 Table 3 requires $10^{-7} \leq PFH < 10^{-6}$ per hour — reflecting the need for continuous availability rather than readiness for infrequent demands.