PRACTICE EXAM 10: 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 0–100 in H_2O at a maximum flow of 600 gpm. The transmitter output reads 12 mA. What is the actual flow rate?

A. 300 gpm

B. 519 gpm

C. 424 gpm

D. 180 gpm

2. A Pt100 RTD reads 138.5 Ω. Using the linear approximation $R(T) = 100(1 + 0.00385T)$, what is the indicated process temperature?

A. 100°C

B. 85°C

C. 115°C

D. 138°C

3. According to ANSI/ISA-5.1, which instrument tag represents a temperature switch high in loop 315?

A. TT-315

B. TIC-315

C. TRC-315

D. TSH-315

4. A DP level transmitter on an open vessel contains liquid at SG = 0.95 with a measurement span of 6 feet. What is the transmitter URV in inches H_2O?

A. 72.0 in H_2O

B. 68.4 in H_2O

C. 56.7 in H_2O

D. 76.0 in H_2O

5. A custody transfer application measures ultra-high-purity semiconductor process gas (SF_6, MW = 146) at low flow rates of 2–20 SLPM. Which technology provides direct mass flow measurement independent of gas composition?

A. Coriolis mass flowmeter

B. Thermal mass flowmeter calibrated for SF_6

C. Orifice plate with molecular weight compensation

D. Positive displacement volumetric meter

6. A thermowell has a tip diameter of 0.5 inches. The process stream velocity is 120 ft/s. Using a Strouhal number of 0.22, what is the vortex shedding frequency?

A. 126.7 Hz

B. 317 Hz

C. 475 Hz

D. 634 Hz

7. A 4-wire Pt100 RTD has two current-source leads (5 Ω and 4 Ω resistance) and two voltage-sensing leads. What temperature measurement error do these unequal lead resistances introduce?

A. 23.4°C high from total series resistance

B. 2.6°C high from the resistance imbalance

C. No error — 4-wire connection eliminates all lead resistance effects

D. 13.0°C high from the larger lead resistance only

8. A flow meter is calibrated against a reference standard with ±0.2% uncertainty. The meter shows ±0.15% errors across its calibrated range. What is the combined measurement uncertainty?

A. 0.05%

B. 0.25%

C. 0.35%

D. 0.18%

9. A turbine flowmeter has a K-factor of 75 pulses per gallon. A batch counter accumulates 112,500 pulses. What volume was transferred?

A. 750 gallons

B. 8,437 gallons

C. 1,500 gallons

D. 3,000 gallons

10. An ORP sensor reads –350 mV in a process stream. What does this negative ORP value most directly indicate?

A. Acidic conditions with pH below 5.0

B. Dissolved oxygen above the sensor measurement range

C. Inadequate disinfectant concentration in the water

D. Strongly reducing conditions in the process stream

11. A nuclear level switch is set to trip at 850 counts/second. The empty vessel reading is 1,200 counts/second and the full vessel reading is 450 counts/second. The current count rate is 900 counts/second. What does this reading indicate?

A. Level has exceeded the switch trip point and the switch has activated

B. Level is below the switch setpoint — count rate has not dropped to the 850 trip threshold

C. The radiation source has weakened and requires replacement

D. Slurry density has increased above the calibrated value

12. A DP level transmitter on a closed vessel shows a constant unchanging reading despite actual level changes in the vessel. Which cause is most likely?

A. The high-pressure impulse line is completely blocked

B. The transmitter zero has been programmed to a fixed value

C. The DCS scaling has an incorrect span setting

D. The wet leg fluid has been contaminated with process condensate

13. A process requires flow measurement of liquid chlorine at –35°C, 50 psig, and 100 gpm. The fluid is non-conductive and corrosive. Which technology is most appropriate?

A. Magnetic flowmeter with titanium electrodes

B. Variable-area rotameter with corrosion-resistant float

C. Coriolis mass flowmeter with Hastelloy wetted parts

D. Vortex flowmeter with PTFE-lined body

14. A dual-input temperature transmitter receives signals from two Pt100 RTDs: inlet = 28.5°C, outlet = 85.3°C. The transmitter calculates the differential temperature directly. What is the ΔT output?

A. 113.8°C

B. 56.8°C

C. 28.5°C

D. 42.2°C

15. An acoustic leak detection system monitors a high-pressure gas pipeline for leaks. At what frequency range does a true gas leak generate its characteristic ultrasonic emission?

A. Infrasound below 20 Hz from pressure wave reflections

B. Audible range 500 Hz to 5 kHz from turbulent flow noise

C. Subsonic range 20–200 Hz from pipe vibration resonance

D. Ultrasonic range above 20 kHz from the turbulent gas jet through the leak orifice

16. A conductivity transmitter on a boiler feedwater system reads 1,450 µS/cm. The normal specification is below 100 µS/cm. What is the most immediate required action?

A. Investigate for condensate leak or ion exchanger breakthrough

B. Recalibrate the conductivity cell against fresh standard solutions

C. Increase chemical treatment dosing to compensate

D. Flush the feedwater system and restart the measurement

17. In ANSI/ISA-5.1, which succeeding letter designates the function of "Totalize" or "Integrate"?

A. R

B. I

C. Q

D. T

18. A DP flow transmitter measures across a venturi tube. At 50% of maximum flow, what percentage of full-scale differential pressure does the venturi produce?

A. 50%

B. 25%

C. 70.7%

D. 10%

19. A plant calibrates field transmitters by comparing their output to portable NIST-traceable reference standards. Which transmitter parameter cannot be verified by this static comparison method alone?

A. Dynamic response time to step input changes

B. Zero error at the lower range value

C. Span error at the upper range value

D. Linearity error at mid-range calibration points

20. A magnetic flowmeter measuring a conductive slurry develops non-conductive polymer buildup on its electrodes over several months of service. What measurement effect does this coating most directly produce?

A. Increasingly high flow readings as the coating narrows the bore

B. Oscillating high-low readings from alternating electrode coating

C. No effect — magmeters measure fluid velocity independent of electrode surface

D. Erratic or degraded measurement as coating resistance exceeds the amplifier input impedance limit

21. According to ANSI/ISA-5.1, which function does the tag "FFY-415" identify?

A. A flow fraction transmitter on loop 415

B. A flow ratio computing relay or converter on loop 415

C. A field-mounted flow indicator on loop 415

D. A fail-safe flow controller with ratio output on loop 415

22. A Pt100 RTD is specified as IEC 60751 Class B with accuracy ±(0.30 + 0.005|T|)°C. What is the maximum allowable error at 200°C?

A. ±1.30°C

B. ±0.80°C

C. ±1.75°C

D. ±0.55°C

DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)

23. A reverse-acting pressure controller has Kc = 2.5 and bias = 55%. The setpoint is 100 psig and the PV is 94 psig. What is the current controller output?

A. 40%

B. 55%

C. 70%

D. 85%

24. An IEC 61131-3 Ladder Diagram rung contains a normally closed contact from its own output coil in series with the rung. What function does this self-contact create?

A. The coil latches until explicitly reset by an unlatch instruction

B. The coil sinks current proportional to the analog input signal level

C. A one-scan delay is introduced between input change and coil response

D. A self-interrupting circuit that prevents continuous coil energization

25. A process bump test yields Kp = 3.0, τ = 45 s, θ = 15 s. Using the Ziegler-Nichols open-loop PID formula $K_c = 1.2\tau/(K_p \times \theta)$, what is the recommended Kc?

A. 0.60

B. 1.20

C. 1.80

D. 2.40

26. A proportional-only steam pressure controller has Kc = 4.0 and bias = 50%. At steady state, the PV is 3 psig below the setpoint. What is the steady-state controller output?

A. 50%

B. 54%

C. 58%

D. 62%

27. In cascade control terminology, what is the "primary" controller?

A. The outer-loop controller whose output sets the inner-loop setpoint

B. The inner-loop controller that directly manipulates the final element

C. The controller with the highest proportional gain setting

D. The first controller installed before the cascade upgrade

28. How many independent parameters are required to fully characterize a first-order-plus-dead-time (FOPDT) process model?

A. One

B. Two

C. Three

D. Four

29. A ratio control station maintains an air-to-fuel ratio of 4.5:1. Fuel flow (wild stream) measures 800 kg/hr. What is the required air flow setpoint?

A. 177.8 kg/hr

B. 3,600 kg/hr

C. 4,800 kg/hr

D. 1,600 kg/hr

30. A controller is in automatic at 80% output. The operator switches to manual and holds at 60%. After 15 minutes, the operator returns to automatic with bumpless transfer enabled. What is the output at the moment of transfer?

A. 80% — restored to last automatic output

B. 70% — averaged between manual and automatic values

C. 60% — initialized from the current manual output value

D. 50% — reset to the neutral bias position

31. Per IEC 62443, Security Level 3 (SL-3) is designed to protect against threats using what category of means?

A. Unintentional or accidental security violations

B. Intentional violation using simple means with minimal resources

C. State-sponsored attacks with extensive resources

D. Intentional violation using sophisticated means with moderate resources

32. Using lambda tuning with $K_c = \tau/(K_p \times (\lambda + \theta))$, calculate K_c for: $K_p = 1.5$, $\tau = 120$ s, $\theta = 40$ s, $\lambda = 80$ s.

A. 0.667

B. 1.00

C. 0.50

D. 1.33

33. A DCS scan rate is 500 ms. A process variable oscillates at 0.8 Hz. Does the 500 ms scan rate satisfy the Nyquist sampling criterion?

A. No — 500 ms scan falls below the Nyquist minimum

B. No — aliasing occurs at any scan rate below the signal frequency

C. Yes — but only if an anti-aliasing filter is added at the input

D. Yes — the 2.0 Hz sampling rate exceeds the 1.6 Hz Nyquist minimum

34. A process has dead time $\theta = 4$ minutes and time constant $\tau = 5$ minutes, giving $\theta/\tau = 0.8$. Which statement most accurately characterizes this process?

A. Excellent controllability — dead time is much less than the time constant

B. Moderately difficult controllability — significant dead time requires conservative tuning

C. No controllability concern — the ratio is below the critical value of 1.0

D. Inherently unstable — requires a Smith Predictor to achieve stable control

35. According to ISA-18.2, what is the recommended maximum alarm rate during normal steady-state plant operations?

A. No more than 1 alarm per 10 minutes

B. No more than 5 alarms per 10 minutes

C. No more than 10 alarms per 10 minutes

D. No more than 3 alarms per hour

36. A direct-acting flow controller (Kc = 2.0, Ti = 30 s) returns from manual to automatic without bumpless transfer. The PV is at setpoint and the manual output was 35% versus the prior automatic integral state of 48%. What occurs at the moment of transfer?

A. Output remains at 35% and gradually integrates toward 48%

B. Output immediately jumps to the bias value of 50%

C. Output bumps from 35% toward the accumulated integral state from the prior automatic period

D. Output resets to zero then climbs to the calculated automatic value

37. In IEC 61131-3 Structured Text, what does the RETAIN variable qualifier specify?

A. The variable is read-only throughout program execution

B. External HMI and SCADA systems cannot write to the variable

C. The variable scope is limited to within a single function block instance

D. The variable retains its last value across controller power cycles and restarts

38. A level control loop output cycles between 30% and 70% at approximately 2-minute intervals with PV and setpoint both constant. Derivative action is disabled. What is the most likely cause?

A. Process dead time exceeding the integral time constant

B. Proportional gain at the ultimate gain stability boundary

C. Control valve mechanical dead band causing integral-driven limit cycling

D. DCS communication lag aliasing the level measurement

39. A split-range arrangement spans a make-up valve from 0–50% controller output (fully closed at 0%, fully open at 50%). At 35% controller output, what is the make-up valve position?

A. 70% open

B. 35% open

C. Fully closed

D. Fully open

40. A model predictive controller executes every 2 minutes with a 30-minute prediction horizon. A measured feed disturbance enters the unit at t = 0 and is predicted to affect product composition in 18 minutes. When does MPC begin applying counteracting control moves?

A. At t = 18 minutes when the disturbance reaches the composition measurement

B. At the next execution at t = 2 minutes — the disturbance falls within the prediction horizon

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

D. Only after composition deviation exceeds the controller deadband

41. The Ziegler-Nichols closed-loop method yields Ku = 6.0 and Pu = 120 seconds. What are the recommended PID controller settings?

A. Kc = 3.6, Ti = 80 s, Td = 20 s

B. Kc = 2.7, Ti = 100 s, Td = 15 s

C. Kc = 3.6, Ti = 120 s, Td = 30 s

D. Kc = 3.6, Ti = 60 s, Td = 15 s

42. An ISA-101 high-performance HMI design review finds that a process overview display uses bright red for all normally running equipment. What is the most critical finding?

A. Red is reserved for alarms — using it for normal operations destroys alarm salience

B. The color palette exceeds the ISA-101 maximum of eight recommended colors

C. The color scheme does not match the facility's existing analog panel design

D. Red equipment indicators may cause false alarm acknowledgements by operators

43. A cascade scheme has an outer composition controller ($\tau \approx 30$ min) and inner temperature controller ($\tau \approx 2$ min). The inner Ti = 30 s and the outer Ti = 45 min. Which statement best characterizes this tuning?

A. Inner loop too slow — Ti should be reduced for effective cascade performance

B. Outer loop too fast — outer Ti must exceed the inner closed-loop time constant

C. Appropriate cascade tuning — inner loop is approximately 10× faster than the outer loop

D. Both loops require retuning to reflect their respective process time constants

44. A statistical process control X-bar chart shows eight consecutive measurements all above the target mean, with all points within the $\pm 3\sigma$ control limits. What action is required per Western Electric rules?

A. No action — all points are within the control limits

B. Investigate for a special cause — 8 consecutive points on one side signal a non-random shift

C. Recalculate control limits using only the most recent eight data points

D. Increase sampling frequency until the pattern reverses

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

45. An equal percentage control valve has Cv_max = 100 and rangeability of 50:1. Using the formula Cv = Cv_min × R^x, what is the approximate Cv at 60% travel?

A. 60.0

B. 50.0

C. 35.4

D. 21.0

46. A conventional spring-loaded PRV set at 150 psig has a specified blowdown of 7%. At what inlet pressure does the valve reseat after a relief event?

A. 143.0 psig

B. 145.5 psig

C. 139.5 psig

D. 130.5 psig

47. Which type of control valve trim produces a linear relationship between stem travel and flow coefficient (Cv)?

A. Equal percentage trim

B. Linear trim

C. Quick-opening trim

D. Parabolic trim

48. A pneumatic diaphragm actuator must overcome 400 lbf of unbalanced fluid force plus 100 lbf of packing friction. Available instrument air is 50 psi. What minimum effective diaphragm area is required?

A. 10.0 in^2

B. 8.0 in^2

C. 12.5 in^2

D. 20.0 in^2

49. A control valve sizing calculation yields Cv_required = 28. The engineer selects a 3-inch globe valve with Cv_rated = 72 at full open. At what percentage of rated Cv does this valve operate at design conditions?

A. 56%

B. 28%

C. 72%

D. 39%

50. During commissioning, a motor-operated valve actuator trips its torque limit switch before the valve fully closes, stopping at 97% of required travel. What is the most likely adjustment needed?

A. Increase the torque limit switch setting to allow greater closing force

B. Reduce supply voltage to the motor to increase available torque

C. Install a larger motor rated for the higher seating torque

D. Reprogram the limit switch to accept 97% travel as the closed position

51. A centrifugal pump operates at 1,500 rpm consuming 120 kW. A VSD reduces speed to 1,200 rpm. What is the new shaft power?

A. 48.0 kW

B. 61.4 kW

C. 76.8 kW

D. 96.0 kW

52. A valve positioner converts a 4–20 mA input to a 3–15 psi pneumatic output. At 10 mA input, what is the pneumatic output?

A. 6.75 psi

B. 8.25 psi

C. 7.50 psi

D. 9.00 psi

53. A spring-to-close pneumatic actuator (air-to-open design) loses instrument air supply. In what position does the connected process valve fail?

A. Closed

B. Open

C. At the position held before air failure

D. At the midpoint of travel as spring and residual air balance

54. An API 527 seat leakage test is performed on a soft-seated PRV (Class III, bubble-tight) at 90% of set pressure. What is the maximum allowable leakage?

A. 40 bubbles per minute

B. 20 bubbles per minute

C. 10 bubbles per minute

D. Zero visible leakage

55. A globe valve with linear trim has Cv_max = 60. What is the Cv at exactly 40% travel?

A. 36.0

B. 15.0

C. 24.0

D. 48.0

56. A double-seated globe valve uses two plugs and two seats on a single stem. What is the primary functional benefit of this balanced-plug design?

A. Higher maximum Cv for a given body size compared to single-seated designs

B. Reduced net unbalanced force enabling smaller actuators than single-seated equivalents

C. Better shutoff class than single-seated designs at the same actuator thrust

D. Mechanical stops at both fully open and fully closed positions

57. Per API 520, a rupture disc is installed immediately upstream of a spring-loaded PRV. What correction factor must be applied to the PRV's certified discharge coefficient for the combined assembly?

A. Kc = 0.90

B. Kc = 1.10

C. Kc = 0.85

D. Kc = 1.00

58. A control valve is required for cryogenic liquid nitrogen service at –196°C. Which body material is most appropriate?

A. Carbon steel (ASTM A216 WCB)

B. Chrome-molybdenum alloy steel (1.25Cr-0.5Mo)

C. Cast iron

D. Austenitic stainless steel (Type 304 or 316)

59. A vessel's MAWP is re-rated from 200 psig to 220 psig. The existing PRV is set at 195 psig. What action is required for the PRV following the re-rating?

A. The PRV remains compliant with no action — set pressure (195) is below new MAWP (220)

B. A formal review is required to confirm continued PRV adequacy for the new MAWP and update documentation

C. The PRV must be replaced with a valve certified to the higher MAWP rating

D. No action is required — PRV compliance is assessed only at initial installation

60. A normally-energized-to-open ESD solenoid valve (energize-to-open) experiences a plant-wide power failure. What position does the connected spring-return ESD valve assume?

A. Remains open — last position mechanically latched by the valve gear

B. Partially closes based on residual instrument air pressure

C. Closes — solenoid de-energizes on power loss and spring drives the valve to the closed safe state

D. Opens fully — power loss opens an additional pneumatic path to the actuator

61. Which NEC hazardous area classification designates locations where flammable vapors exist continuously or for long periods during normal operations?

A. Class I, Division 1

B. Class I, Division 2

C. Class II, Division 1

D. Zone 1 (IEC classification equivalent)

62. A VSD drives a centrifugal pump at 75% of rated speed. Using the affinity law for head, what percentage of rated head does the pump develop?

A. 75%

B. 56%

C. 42%

D. 32%

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

63. A 24 VDC loop supplies a HART transmitter through a 250 Ω input resistor, 75 Ω IS barrier, and 180 Ω cable loop resistance. The transmitter requires minimum 12 VDC. Is loop compliance confirmed at 20 mA?

A. No — total 505 Ω exceeds the maximum 500 Ω loop resistance

B. No — the transmitter receives only 12.0 VDC, exactly at its minimum

C. Yes — the transmitter receives 15.0 VDC, well above minimum

D. Yes — the transmitter receives 13.9 VDC, exceeding the 12 VDC minimum

64. A PROFIBUS DP network at 12 Mbit/s is terminated at both cable ends with 100 Ω resistors instead of the correct 120 Ω. What problem results?

A. The termination resistors overheat and eventually open the bus circuit

B. Maximum addressable device count reduces from 32 to 24 without correct termination

C. Impedance mismatch causes signal reflections that corrupt data at this high baud rate

D. The segment automatically reduces baud rate to 1.5 Mbit/s to compensate

65. A 3 km single-mode fiber optic link connects a DCS building to a remote pump station through a high-EMI electrical switchyard. What is the primary advantage of fiber over shielded copper cable for this installation?

A. Complete electromagnetic immunity and galvanic isolation between the two buildings

B. Lower installation cost per meter than shielded twisted pair cable

C. Higher data throughput than any copper cable technology in this application

D. No intermediate repeaters required for any fiber run below 10 km

66. A HART communicator reads a transmitter's polling address as zero. What does address zero indicate?

A. The transmitter is in a fault state and cannot communicate

B. The transmitter firmware requires updating before address assignment

C. The transmitter is in point-to-point mode — address zero is the standard non-multidrop address

D. The transmitter has been reset to factory defaults requiring full reconfiguration

67. A Modbus RTU network with 8 RS-485 slave devices is operating normally. Which single failure would cause all 8 devices to become simultaneously unreachable?

A. One slave device failing in a state that actively drives the bus high

B. RS-485 bus termination failure at the master end degrading signal quality across the full segment

C. One slave device with an address conflicting with another slave

D. A baud rate mismatch in a single slave device

68. A DCS analog output card drives a 4–20 mA signal to a field valve positioner through 350 meters of cable with 0.15 Ω per meter per conductor. What is the total cable resistance added to the loop?

A. 52.5 Ω

B. 350 Ω

C. 150 Ω

D. 105 Ω

69. Per IEC 62443, Security Level 2 (SL-2) requires which specific access control capability for privileged human users?

A. Multi-factor authentication for privileged access accounts

B. Biometric authentication at all operator access points

C. Complex password-only authentication with 90-day expiration

D. Anonymous read-only access with logged write access for operators

70. A data diode is installed between the OT DCS historian and the IT business network. Which communication direction does this hardware device physically enforce?

A. Bidirectional with deep packet inspection filtering malicious commands

B. IT to OT only — business systems push data requests to the historian

C. OT to IT only — process data flows one way to business systems

D. Bidirectional with time-delay buffering that prevents real-time command injection

71. An OT network VLAN audit reveals that a manufacturing execution system server has trunk port connectivity to both VLAN 10 (safety controllers) and VLAN 20 (operator workstations). What is the primary security concern?

A. VLAN trunk links reduce available bandwidth for safety controller communication

B. A single switch failure could simultaneously affect both VLANs

C. Manufacturing execution systems are not certified for connection to safety networks

D. A compromised MES server gains simultaneous network access to both the safety controller VLAN and the operator VLAN

72. A 16-bit ADC processes a 0–200°C temperature range. What is the minimum resolvable temperature increment?

A. 0.024°C

B. 0.003°C

C. 0.012°C

D. 0.050°C

73. Per NAMUR NE 43 signal conventions, what does a 4–20 mA loop reading below 3.6 mA indicate?

A. Process variable is below the transmitter lower range value

B. Loop power supply voltage is insufficient for transmitter operation

C. Open circuit, broken wire, or transmitter hardware failure

D. Transmitter is in self-test mode performing internal diagnostics

74. Foundation Fieldbus H1 operates at 31.25 kbit/s. What is the maximum cable segment length for an H1 segment using standard instrument cable?

A. 1,900 meters

B. 1,200 meters

C. 500 meters

D. 2,500 meters

75. A DCS historian server is encrypted by a ransomware attack. The incident response plan is activated. Which recovery action should be performed first?

A. Pay the ransom to obtain the decryption key and restore historian data

B. Reformat the historian server and reinstall the operating system from media

C. Disconnect all OT network equipment to contain potential spread to other systems

D. Isolate the affected system and restore the historian from the most recent clean backup

DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)

76. Per IEC 61511, a SIF operating in low-demand mode with a SIL 2 requirement must achieve PFD_avg in what numerical range?

A. $0.1 > PFD \geq 0.01$

B. $0.01 > PFD \geq 0.001$

C. $0.001 > PFD \geq 0.0001$

D. $PFD < 0.0001$

77. A 1oo1 pressure transmitter has $\lambda_{DU} = 2\times10^{-6}$/hr and is proof tested every 6 months (TI = 4,380 hr). What is the PFD_avg?

A. 8.76×10^{-3}

B. 1.75×10^{-2}

C. 4.38×10^{-3}

D. 2.19×10^{-3}

78. A SIF achieves a calculated PFD_avg = 6.5×10^{-3} against a SIL 2 requirement. Does the SIF comply?

A. No — SIL 2 requires PFD below 5.0×10^{-3}

B. Yes — 6.5×10^{-3} falls within the SIL 2 range of 0.001 to 0.01

C. No — SIL 2 requires PFD below 1×10^{-3}

D. Yes — but additional 3-month proof testing is required to maintain compliance

79. A HAZOP identifies a reactor cooling failure with initiating event frequency = 0.5/year. The existing BPCS PFD = 0.1. Risk tolerance = 5×10^{-3}/year. Is a SIF required, and if so, what is the required PFD?

A. Yes — required SIF PFD = 0.10 at the SIL 1 upper boundary

B. No — BPCS alone reduces risk below the 5×10^{-3}/year tolerance

C. Yes — required SIF PFD = 0.01 (SIL 2 required)

D. Yes — required SIF PFD = 0.001 (SIL 3 required)

80. A 2oo3 SIS configuration uses three transmitters each with $\lambda\_DU = 4\times10^{-6}$/hr and TI = 8,760 hr ($\beta$ = 0). Using the formula PFD = $(\lambda\_DU \times TI)^2$, what is the independent failure PFD_avg?

A. 3.07×10^{-4}

B. 6.14×10^{-4}

C. 1.75×10^{-2}

D. 1.23×10^{-3}

81. During a SIF proof test, a technician applies simulated high pressure to the sensor, observes the SIS logic solver output activate, and records the test as passed. What critical proof test element was omitted?

A. Verification that the DCS received and logged the SIS trip signal

B. Verification that the ESD valve achieved its required safe position within the SRS-specified response time

C. Verification that the SIS logic solver alarm was acknowledged by the control room operator

D. Verification that the sensor calibration matches the SRS-specified trip setpoint value

82. IEC 61511 Edition 2 integrated cybersecurity requirements into the SIS lifecycle. Which specific cybersecurity element is required within the SIS documentation?

A. Annual penetration testing of all SIS network segments by a certified assessor

B. Encryption of all fieldbus communications between SIS sensors and logic solvers

C. Physical separation of all SIS equipment from any network-connected device

D. A security risk assessment documenting threats to the SIS and countermeasures in the SRS

83. A SIF achieves PFD_avg = 4.5×10^{-3} using three identical pressure transmitters from the same manufacturer. Adding a fourth identical transmitter from the same manufacturer is proposed. What concern must be raised?

A. A fourth transmitter requires 4oo4 voting logic not addressed in IEC 61511

B. Four identical transmitters require simultaneous proof testing, creating operational downtime risk

C. Identical transmitters from the same manufacturer share common cause failure modes — added same-type redundancy provides limited benefit when CCF dominates

D. SIL 2 is already achieved and additional redundancy introduces unnecessary complexity

84. Per IEC 61511, the "Design and Engineering" lifecycle phase produces which primary output document?

A. Detailed SIS design specification including logic diagrams, cause-and-effect matrices, and hardware descriptions

B. Safety requirements specification defining functional requirements for each SIF

C. SIL verification report confirming the designed SIF achieves the required PFD

D. Hazard and risk assessment identifying hazardous scenarios and SIL targets

85. A proof test finds that an ESD valve achieves only 80% of required closure travel and stops. The test is recorded as failed. What must occur before returning the SIF to service?

A. Reduce the proof test interval to every 3 months until the valve is fully repaired

B. Accept 80% closure if the residual opening cannot directly cause the identified hazard

C. Repair the valve to full closure travel and retest the complete cause-to-effect path before returning to service

D. Document the partial closure and update the PFD calculation to account for reduced valve effectiveness

PRACTICE EXAM 10: ANSWER KEY AND EXPLANATIONS

1. C — Without square root extraction, output is proportional to DP. At 12 mA (50% of span), DP = 50 in H_2O. Actual flow = 600 × √(50/100) = 600 × 0.707 = 424 gpm. The square root relationship between DP and flow means 50% DP corresponds to only 70.7% of maximum flow.

2. A — Solving for T: 138.5 = 100(1 + 0.00385T) → 1.385 = 1 + 0.00385T → T = 0.385/0.00385 = 100°C. The Pt100 standard value at 100°C is 138.5 Ω, making this a useful calibration verification point.

3. D — Per ANSI/ISA-5.1: T = Temperature, S = Switch, H = High. TSH = Temperature Switch High — a device whose output changes discrete state when temperature exceeds a defined high threshold. TT designates a transmitter; TIC and TRC include controller and recorder functions respectively.

4. B — URV = SG × h × 12 in/ft = 0.95 × 6 × 12 = 68.4 in H_2O. The SG multiplier corrects for the denser-than-water fluid generating proportionally more hydrostatic pressure per foot of height than the water-reference definition of in H_2O.

5. A — Coriolis meters measure mass flow through the Coriolis force on a vibrating tube, completely independent of gas composition, density, or viscosity. Thermal mass flowmeters require gas-specific calibration and recalibration when gas composition changes — making them unsuitable for variable-composition semiconductor gas applications.

6. D — $f_w = St \times V/d$. Convert tip diameter: 0.5 in ÷ 12 = 0.04167 ft. $f_w = 0.22 \times 120/0.04167 = 26.4/0.04167 = 633.6 \approx 634$ Hz. This frequency must satisfy the ASME PTC 19.3 TW frequency ratio criterion $r < 0.8$ against the thermowell natural frequency.

7. C — Four-wire RTD measurement uses two separate wire pairs — one pair carries the excitation current and the other pair senses voltage across the RTD element only. Because no current flows through the sensing wires, their resistance creates no voltage drop, completely eliminating all lead resistance effects regardless of imbalance.

8. B — Combined uncertainty = $\sqrt{(0.2^2 + 0.15^2)} = \sqrt{(0.04 + 0.0225)} = \sqrt{0.0625} = 0.25\%$. Independent uncertainties combine using root-sum-of-squares, not simple addition, because they are statistically independent random variables that do not always add in the same direction.

9. C — Volume = pulses / K-factor = 112,500 / 75 = 1,500 gallons. The K-factor represents the meter's pulse-per-unit-volume calibration constant — dividing accumulated pulse count by K-factor directly yields transferred volume.

10. D — ORP (Oxidation-Reduction Potential) measures the tendency of a solution to accept or donate electrons. Negative ORP values indicate a reducing environment — excess reducing agents that will donate electrons. This contrasts with positive ORP indicating oxidizing conditions; the value is not a direct measure of pH.

11. B — The switch is set to trip at 850 counts/second (the level threshold). Current count rate is 900 counts/second — above the 850 trip point. Because higher count rate means less gamma attenuation, which means lower level (less fluid in the beam path), 900 counts/second indicates level is below the trip setpoint and the switch has not yet activated.

12. A — A completely blocked high-pressure impulse line severs the process pressure signal from the HP port, leaving only the wet leg pressure on the LP side. The transmitter reads a fixed value regardless of actual level changes because the HP input cannot change without a connected fluid path to the process.

13. C — Liquid chlorine is non-conductive (eliminating magnetic flowmeters), at cryogenic temperature (eliminating most rotameters), and highly corrosive. Coriolis meters with Hastelloy wetted materials provide direct mass flow measurement compatible with corrosive cryogenic liquids across the full viscosity and density range.

14. B — $\Delta T = T\_outlet - T\_inlet = 85.3 - 28.5 = 56.8°C$. The dual-input transmitter subtracts the two RTD inputs directly. This direct differential measurement avoids the large subtraction error that would result from independently calibrated single-input transmitters.

15. D — Gas leaking through a small orifice under pressure creates a highly turbulent jet that generates acoustic emissions predominantly in the ultrasonic range above 20 kHz. Ultrasonic detection at these frequencies provides high sensitivity and localization capability while rejecting audible-range background noise from normal plant operations.

16. A — Normal boiler feedwater conductivity below 100 µS/cm should essentially register near-zero ionic content. A jump to 1,450 µS/cm represents a 14× exceedance that is characteristic of a major contamination event — condensate leak returning process chemicals or complete ion exchanger exhaustion requiring immediate investigation to prevent boiler damage.

17. C — Per ANSI/ISA-5.1, the succeeding letter "Q" designates Quantity — a totalized or integrated measurement. Examples: FQ (Flow Totalizer), LQ (Level Totalizer). "R" designates Recording; "I" designates Indicating; "T" designates Transmitter.

18. B — Flow through any DP primary element is proportional to $\sqrt{\Delta P}$. At 50% of maximum flow: $\Delta P = (0.50)^2 \times$ full-scale DP $= 0.25 \times 100\% = 25\%$ of full-scale DP. At 50% flow the venturi produces

only 25% of full-scale DP — demonstrating the nonlinear relationship between flow and differential pressure.

19. A — Static calibration compares steady-state output values against reference standards. Dynamic response time (the rate at which the transmitter output follows rapid input changes) requires a step or frequency-response test with time-resolved measurement — cannot be determined from comparing two static steady-state points.

20. D — Magnetic flowmeters measure the EMF induced in the flowing conductor (process fluid). Electrode coating increases the resistance between the fluid and the amplifier input. When coating resistance exceeds the amplifier's input impedance, the measurement circuit is effectively broken and output becomes erratic or unreliable.

21. B — Per ANSI/ISA-5.1: the first "F" = Flow (measured variable), second "F" = Ratio (function modifier), Y = Relay, computer, or converter. FFY identifies a flow ratio computing relay or converter — a device that calculates and outputs a flow ratio signal in loop 415.

22. A — Accuracy = ±(0.30 + 0.005 × 200) = ±(0.30 + 1.00) = ±1.30°C. The temperature-proportional term grows with temperature, making Class B accuracy increasingly loose at higher process temperatures — an important consideration when selecting RTD accuracy class for elevated temperature measurements.

23. C — For reverse-acting controller: output = bias + Kc × (SP − PV) = 55 + 2.5 × (100 − 94) = 55 + 15 = 70%. Reverse-acting increases output when PV falls below setpoint, which is correct for applications where higher output opens a heating or supply valve.

24. D — A normally closed self-contact (output coil contact in series with its own rung) creates a self-interrupting circuit. When the coil energizes, the NC self-contact opens, de-energizing the coil. The coil then de-energizes, the NC contact re-closes, and the cycle repeats — producing a pulse or oscillating output.

25. B — $K_c = 1.2\tau/(K_p \times \theta) = 1.2 \times 45/(3.0 \times 15) = 54/45 = 1.20$. This Z-N PID gain targets quarter-decay ratio response. The 1.2 multiplier for PID settings (vs. 0.9 for PI) reflects the derivative term's contribution to stability, allowing higher proportional gain without instability.

26. D — Proportional-only controller output = bias + Kc × error = 50 + 4.0 × 3 = 62%. The 3 psig steady-state error below setpoint is unavoidable with proportional-only control — it is the error required to maintain the 12% output offset above bias needed to hold the current valve position.

27. A — In cascade control, the primary (outer) controller monitors the main process variable (e.g., temperature, composition) and generates an output that becomes the setpoint for the secondary (inner) controller. The secondary controller directly manipulates the final control element — the primary controls the primary; secondary manipulates.

28. C — The FOPDT model requires exactly three parameters: process gain (Kp), time constant (τ), and dead time (θ). These three parameters completely characterize the process dynamics for control loop analysis, stability assessment, and controller tuning calculations.

29. B — Air setpoint = ratio × fuel flow = 4.5 × 800 = 3,600 kg/hr. The ratio station multiplies the wild stream (fuel) by the configured ratio factor to generate the controlled stream (air) setpoint. This maintains the stoichiometric air-to-fuel ratio regardless of fuel flow variations.

30. C — Bumpless transfer initializes the controller's integral state to match the current manual output value before enabling automatic. At the moment of transfer, the calculated automatic output equals the 60% manual output — the controller then smoothly adjusts from this point as the error develops.

31. D — IEC 62443 Security Level 3 addresses intentional violation by sophisticated adversaries using moderate resources — including organized groups with significant technical capability. SL-1 covers unintentional violations, SL-2 covers simple intentional attacks, and SL-4 covers state-sponsored advanced persistent threats.

32. A — $K_c = \tau/(K_p \times (\lambda + \theta)) = 120/(1.5 \times (80 + 40)) = 120/(1.5 \times 120) = 120/180 = 0.667$. Selecting $\lambda = 2\theta$ produces a moderately conservative design — the closed-loop time constant is twice the dead time, balancing performance and robustness.

33. D — Nyquist criterion requires sampling rate ≥ 2× signal frequency: 2 × 0.8 Hz = 1.6 Hz minimum. A 500 ms scan provides 1/0.5 = 2.0 Hz sampling rate. Since 2.0 Hz ≥ 1.6 Hz, the Nyquist criterion is satisfied — the 0.8 Hz process oscillation can be faithfully represented.

34. B — A θ/τ ratio of 0.8 indicates significant dead time relative to the time constant — dead time represents 44% of the total process response time ($\theta/(\theta+\tau)$). This moderate ratio requires conservative controller tuning and limits achievable closed-loop performance compared to processes with lower dead time fractions.

35. A — ISA-18.2 defines the performance target for normal steady-state operations as no more than one alarm per 10-minute period. Exceeding this rate during steady operation indicates alarm system design problems requiring rationalization. The rate of 10+ alarms per 10 minutes is classified as unmanageable.

36. C — Without bumpless transfer, the controller retains its prior automatic integral state (48%) rather than initializing to the manual output (35%). At the moment of transfer, the integral state drives a sudden output jump from 35% toward the prior accumulated state — producing a valve bump that disturbs the process.

37. D — The RETAIN qualifier in IEC 61131-3 ST designates variables that survive power cycles by storing their values in non-volatile memory. This is critical for batch counters, production totals, and operator-set parameters that must not reset to default on controller restart or power interruption.

38. C — With constant PV and setpoint, integral action continuously accumulates the zero-error condition — but valve dead band creates a zone where the controller output can change without producing any valve or process response. Integral drives the output across the dead band, the valve jumps, PV changes briefly, and the cycle repeats, producing sustained output oscillation.

39. A — The make-up valve operates from 0% (fully closed) to 50% (fully open) controller output. At 35% output: position = (35/50) × 100 = 70% open. Linear scaling within the assigned sub-range maps controller output fractions directly to valve travel percentage.

40. B — MPC's process model allows it to predict the future impact of a measured disturbance throughout its prediction horizon. At the very next execution (t = 2 minutes), the MPC calculates that the disturbance entering now will affect composition in 18 minutes and begins applying pre-emptive counteracting moves immediately — unlike feedback PID which waits until composition is actually affected.

41. D — Z-N closed-loop PID: Kc = 0.6 × Ku = 0.6 × 6.0 = 3.6. Ti = Pu/2 = 120/2 = 60 s. Td = Pu/8 = 120/8 = 15 s. Option D correctly identifies all three values — options A through C contain errors in Ti, Td, or both.

42. A — ISA-101 reserves high-contrast red exclusively for alarms and abnormal conditions. When red is used for all normally running equipment, operators become desensitized to red and cannot distinguish alarm states from normal operation — destroying the primary visual mechanism for attracting attention to urgent abnormal conditions.

43. C — Inner loop Ti = 30 s (settling ~60–90 s) vs. outer loop Ti = 45 min. The inner loop is approximately 60× faster — well exceeding the minimum 3–5× ratio recommended for stable cascade control. The outer loop is appropriately slower, allowing the inner loop to fully reject inner disturbances before they propagate to the outer composition measurement.

44. B — Western Electric Rule 2 flags 8 or more consecutive points on the same side of the centerline as a special cause signal, even if all points are within ±3σ limits. The non-random run indicates a sustained shift in the process mean requiring investigation for an assignable cause.

45. D — Cv_min = 100/50 = 2.0. At 60% travel: Cv = 2.0 × 50^0.60. log(50) = 1.699; 0.60 × 1.699 = 1.019; 10^1.019 = 10.45. Cv = 2.0 × 10.45 = 20.9 ≈ 21.0. Equal percentage valves have only about 21% of maximum Cv at 60% travel due to the exponential characteristic.

46. C — Blowdown = 7% × 150 psig = 10.5 psi. Reseat pressure = 150 − 10.5 = 139.5 psig. Blowdown is the pressure reduction below set pressure required for the valve to reseat — providing hysteresis that prevents rapid chattering cycles near the set pressure.

47. B — Linear trim is defined by a directly proportional relationship between stem position and Cv. Equal percentage trim produces exponentially increasing Cv with travel; quick-opening produces high initial Cv that rapidly approaches maximum near the beginning of travel.

48. A — Total force = 400 + 100 = 500 lbf. Required area = 500/50 = 10.0 in². Pneumatic force equals supply pressure multiplied by effective diaphragm area — the diaphragm must produce sufficient force to overcome all mechanical and hydraulic forces resisting stem movement.

49. D — Operating Cv/Rated Cv = 28/72 = 38.9% ≈ 39%. Operating within the 20–80% travel range provides adequate rangeability above and below the design point. At 39% of rated Cv, the valve has reasonable control range without the instability associated with operating near either extreme.

50. A — The torque limit switch protects the motor and gearbox from mechanical overload during seating. If it trips before full closure, the setting is insufficient for the required seating torque at operating conditions. Increasing the torque limit switch setting allows the actuator to develop the additional force needed to achieve full valve closure.

51. B — Affinity law for power: $P \propto N^3$. $P_{new} = 120 \times (1{,}200/1{,}500)^3 = 120 \times (0.80)^3 = 120 \times 0.512 = 61.44 \approx 61.4$ kW. The cubic relationship makes speed reduction highly effective for energy savings — a 20% speed reduction cuts power by nearly 49%.

52. C — I/P conversion: 4 mA → 3 psi, 20 mA → 15 psi. At 10 mA: percentage = (10−4)/(20−4) = 6/16 = 37.5%. Pneumatic output = 3 + (0.375 × 12) = 3 + 4.5 = 7.5 psi. Linear interpolation across both signal ranges must be applied consistently.

53. A — Air-to-open (spring-to-close) actuators use instrument air to hold the valve open against a compressed return spring. On loss of air supply, the spring drives the valve to the fully closed position without any control signal or electrical power — this is the inherent fail-safe behavior of the spring-return design.

54. D — API 527 Class III (soft-seated, bubble-tight) requires zero visible leakage at 90% of set pressure. This zero-leakage standard reflects the capability of elastomeric or PTFE soft seats to achieve complete bubble-tight sealing — a standard that metal-seated valves cannot reliably meet.

55. C — Linear trim: $Cv = Cv_{max} \times$ travel fraction = 60 × 0.40 = 24.0. The defining characteristic of linear trim is that Cv varies in direct proportion to stem travel — making mid-range and any-point Cv calculation straightforward.

56. B — Double-ported valves apply inlet pressure to both plugs in opposing directions. The upward force on one plug is largely offset by the downward force on the other, dramatically reducing net unbalanced force on the stem. This balanced design requires significantly smaller actuators compared to single-seat valves handling the same differential pressure.

57. A — Per API 520, when a rupture disc is installed upstream of a PRV in a combination device, a combination correction factor Kc = 0.90 is applied to the PRV's certified discharge coefficient. This 10% capacity reduction accounts for flow disturbance and turbulence introduced by the ruptured disc material in the flow stream.

58. D — Austenitic stainless steel (Type 304 or 316) maintains adequate ductility and impact toughness at cryogenic temperatures down to −269°C due to its face-centered cubic austenitic microstructure. Carbon steel and low-alloy steels undergo ductile-to-brittle transition below approximately −46°C and are unsuitable for cryogenic service.

59. B — Re-rating a vessel to a higher MAWP changes the design parameters against which all pressure relief devices are evaluated. A formal PRV adequacy review is required to confirm the existing valve remains appropriately sized and set for the new MAWP, and documentation must be updated to reflect the re-rated conditions.

60. C — A normally-energized-to-open solenoid holds the actuator air path open during normal powered operations. On power failure, the solenoid de-energizes and shifts to vent the actuator air, allowing the spring to close the ESD valve. This design achieves the fail-safe closed position on any loss of electrical power.

61. A — NEC Article 500 defines Class I, Division 1 as locations where flammable vapors exist continuously, intermittently, or periodically during normal operations. Division 2 covers only abnormal conditions. Class II addresses combustible dusts. Zone 1 is the IEC equivalent to Division 1.

62. B — Affinity law for head: $H \propto N^2$. At 75% speed: $H = (0.75)^2 \times 100\% = 0.5625 \times 100\% = 56.25\% \approx 56\%$ of rated head. Head varies with the square of speed ratio — important for system curve analysis to ensure adequate flow delivery at reduced speed.

63. D — Total resistance = 250 + 75 + 180 = 505 Ω. Voltage drop at 20 mA = 0.020 × 505 = 10.1 V. Transmitter terminal voltage = 24.0 − 10.1 = 13.9 VDC. This exceeds the 12 VDC minimum, confirming loop compliance with 1.9 V margin.

64. C — Correct PROFIBUS RS-485 termination is 120 Ω to match cable characteristic impedance. Using 100 Ω creates an impedance mismatch — the 17% deviation leaves signal energy unreflected at both ends, producing reflections that corrupt data at 12 Mbit/s where bit periods are too short for reflections to decay before the next bit window.

65. A — Single-mode fiber carries optical signals that are completely immune to electromagnetic fields — high-voltage switchyard interference cannot affect a light pulse. Fiber also provides complete galvanic isolation between buildings, eliminating ground loop issues and lightning surge coupling that copper cables are vulnerable to regardless of shielding quality.

66. C — HART addressing uses polling addresses 0–15. Address 0 is the standard configuration for point-to-point (non-multidrop) HART loops where the transmitter simultaneously outputs the normal 4–20 mA analog signal and responds to HART digital communication commands.

67. A — A slave device that actively drives the RS-485 bus high without being addressed (bus contention) prevents all other devices from driving the bus low when transmitting, corrupting

every transmission across the entire segment. A single failed device creating bus contention renders all other devices unreachable.

68. D — Two conductors × 350 m × 0.15 Ω/m = 105 Ω total cable resistance. The factor of two accounts for both the outgoing and return conductors forming the complete current loop — a commonly missed factor in loop resistance compliance calculations.

69. A — IEC 62443 SL-2 specifically requires multi-factor authentication for privileged human user access. This security level addresses intentional attacks using simple means — MFA prevents credential compromise from enabling unauthorized privileged access even if passwords are stolen.

70. C — A data diode is a hardware device that physically implements unidirectional communication — typically using a fiber optic transmitter with no receiver on one side, making reverse-direction transmission physically impossible. Data flows OT → IT only; the business network cannot send data or commands to OT systems.

71. D — A server with trunk connectivity to both VLANs effectively has simultaneous network access to both segments. If a threat actor compromises the MES server, they gain direct network access to both the safety controller VLAN and the operator workstation VLAN simultaneously — bypassing the VLAN segmentation that was designed to limit lateral movement.

72. B — 16-bit ADC resolves into 2^{16} = 65,536 steps. Minimum increment = 200°C / 65,536 = 0.00305°C ≈ 0.003°C. This fine resolution is essential for precise temperature control applications where small deviations must be detected and corrected reliably.

73. C — NAMUR NE 43 defines the fault detection range below 3.6 mA as indicating open circuit, broken wire, or transmitter hardware failure. Normal measurements use 4–20 mA; values below 3.6 mA cannot represent valid process readings and indicate a wiring or hardware fault condition.

74. A — Foundation Fieldbus H1 standard instrument cable supports segments up to 1,900 meters at 31.25 kbit/s. This distance limit reflects the cable's resistance, capacitance, and the signal attenuation budget for reliable communication at this baud rate. Shorter cable types (Type B or C) have reduced maximum lengths.

75. D — The first priority in ransomware response is isolating the affected system to prevent spread, then restoring from the most recent clean backup before the infection. Paying ransom neither guarantees decryption nor removes the malware; formatting and reinstalling before backup restoration would lose recoverable data.

76. B — IEC 61511 SIL 2 in low-demand mode requires 0.001 ≤ PFD_avg < 0.01 — the second-highest safety integrity level for low-demand SIFs. SIL 1 = 0.01–0.1; SIL 3 = 0.0001–0.001; SIL 4 = below 0.0001.

77. C — PFD_avg = λ_DU × TI/2 = $2\times10^{-6} \times 4{,}380/2 = 2\times10^{-6} \times 2{,}190 = 4.38\times10^{-3}$. This falls within the SIL 2 range (0.001–0.01), confirming the six-month proof test interval achieves SIL 2 for this transmitter failure rate.

78. B — SIL 2 requires $0.001 \leq PFD < 0.01$. A PFD_avg of $6.5\times10^{-3} = 0.0065$ falls within this range. The value does not need to be below 5×10^{-3} — any value within the 0.001–0.01 SIL 2 band satisfies the requirement.

79. A — Mitigated frequency with BPCS = 0.5 × 0.1 = 0.05/year. Risk tolerance = 5×10^{-3}/year. Since $0.05 > 5\times10^{-3}$, a SIF is required. Required SIF PFD = $5\times10^{-3}/0.05 = 0.10$ — at the upper boundary of SIL 1 range, confirming SIL 1 is required.

80. D — Using PFD = $(\lambda_{DU} \times TI)^2$: $(4\times10^{-6} \times 8{,}760)^2 = (0.03504)^2 = 1.228\times10^{-3} \approx 1.23\times10^{-3}$. The squared term reflects the probability that two independent channels fail simultaneously in a 2oo3 configuration — the product of two individual PFDs.

81. B — A complete SIF proof test must verify the entire cause-to-effect path: sensor → logic solver → final element achieving the specified safe position within the SRS-specified response time. Testing sensor and logic solver alone without confirming final element closure leaves the most mechanically failure-prone component untested.

82. D — IEC 61511 Edition 2 Clause 8.2.4 requires a security risk assessment that identifies threats to the SIS, assesses the potential for those threats to cause loss of the safety function, and documents countermeasures in the SRS. This explicitly integrates cybersecurity into the functional safety lifecycle documentation.

83. C — Adding identical transmitters from the same manufacturer increases the number of channels susceptible to the same common cause failures — shared design defects, manufacturing variations, environmental sensitivities, and maintenance vulnerabilities. When CCF dominates the PFD (common in SIL 2+ architectures), additional same-manufacturer redundancy provides minimal improvement; technological diversity is more effective.

84. A — The Design and Engineering phase per IEC 61511 produces the detailed SIS design specification — logic diagrams, cause-and-effect matrices, hardware selection, and software design. The SRS was produced in the earlier Analysis phase; SIL verification and hazard assessment are separate lifecycle deliverables.

85. C — A valve achieving only 80% closure cannot perform its safety function — the SRS requires full closure to achieve the defined safe state. The root cause must be identified, the valve repaired to achieve full travel, and the complete cause-to-effect path retested before the SIF is considered validated and returned to service.