Table E-1

Failure Frequencies and Probabilities for Miscellaneous Equipment

"***" indicates a number will be included when available; "—" indicates value not applicable (see Note 1)
explanatory text referred to in notes and footnotes can be found on pages E-23 through E-28

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
AIR SUPPLY (PLANT-WIDE INSTRUMENT AIR SUPPLY)	Loss of air, no pressure (which would render any component or system requiring use of air unavailable)	0.2 / year	—	—	—	R-26
AIR SUPPLY (LOCALLY- REGULATED)	Regulator fails closed	0.03 / year	—	—	—	R-26
	Tubing breaks	0.01 / year	—	—	—	R-26
	Valve closed inadvertently	—	—	—	Use Human Error	—
ALARMS	See Note 7					
ANALYZERS						
CONDUCTIVITY	False reading	0.07 / year	—	—	See Note 8	R-26
	—	—	Fails with safe reading	***	—	—
GAS CHROMATOGRAPHIC	False reading	1.0 / year	—	—	See Note 8	R-26
	—	—	Fails with safe reading	10.0 / year	—	R-26
INFRARED	False reading	0.5 / year	—	—	See Note 8	R-26
	—	—	Fails with safe reading	4.0 / year	—	R-26
LEL (or LOWER EXPLOSIVE LIMIT)	See GAS DETECTORS					
OXYGEN	False reading	0.3 / year	—	—	See Note 8	R-26
	—	—	Fails with safe reading	4.0 / year	—	R-26
STACK OXYGEN	False reading	0.07 / year	—	—	See Note 8	R-26
	—	—	Fails with safe reading	0.2 / year	—	R-26
ARTICULATED ARM	See LOADING ARMS					
BELLOWS, FLEXIBLE	See EXPANSION JOINTS					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
BELT CONVEYOR	Electric motor stops	0.5 / year	—	—	—	R-1
BELT DRIVE	Belt breaks or stops	0.5 / year	—	—	—	R-1
BLOWER	See FAN (EXHAUST, INDUCED-DRAFT, OR FORCED DRAFT)					
BREAKER, CIRCUIT	See CIRCUIT BREAKER					
BUCKET ELEVATOR	Electric motor stops	0.5 / year	—	—	—	R-1
	Buckets fall off belt	0.02 / year	—	—	—	R-1
CCTV	See TV SYSTEM, CLOSED CIRCUIT					
CHECK VALVES	See VALVES, CHECK					
CIRCUIT BREAKER	Fails to interrupt current	—	—	—	0.001 @ 1 yr 0.002 @ 2 yr 0.003 @ 3 yr	R-10
	—	—	Premature interrupt	0.01 / year	—	R-10
CLOSED-CIRCUIT TV SYSTEM	See TV SYSTEM, CLOSED CIRCUIT					
COMPRESSOR, CENTRIFUGAL (I.E. REFRIGERATION, AIR, OR GAS CIRCULATOR)	Fails to Run	0.3 / year	—	—	—	R-26
	Fails to start	—	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-16
COMPRESSOR, RECIPROCATING (I.E. FEED GAS OR MAKEUP GAS)	Fails to Run	0.6 / year	—	—	—	R-26
	Fails to start	—	—	—	0.1 @ 1 yr 0.2 @ 2 yr 0.3 @ 3 yr	R-23

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
CONTROL VALVE	See FINAL CONTROL ELEMENTS					
CONTROLLERS						
LOCAL PNEUMATIC	False output	0.05 / year	—	—	0.025 @ 1 yr 0.05 @ 2 yr 0.075 @ 3 yr	R-26
	—	—	Safe output	0.1 / year	—	R-26
SINGLE LOOP, ANALOG	False output	0.05 / year	—	—	0.025 @ 1 yr 0.05 @ 2 yr 0.075 @ 3 yr	R-26
	—	—	Safe output	0.1 / year	—	R-26
SINGLE LOOP, DIGITAL	False output	0.05 / year	—	—	0.025 @ 1 yr 0.05 @ 2 yr 0.075 @ 3 yr	R-26
	—	—	Safe output	0.1 / year	—	R-26
DCS (Hardware Only) (See Note 10)	False output	0.05 / year	—	—	0.025 @ 1 yr 0.05 @ 2 yr 0.075 @ 3 yr	R-26
	—	—	Safe output	0.1 / year	—	R-26
PLC	Contacts do not open	See PLC LOGIC	—	—	—	—
	—	—	Contacts open prematurely	See PLC LOGIC	—	—
CONVERTER, SIGNAL (for input or output devices)						
I/P or P/I	False output	0.04 / year	—	—	—	R-38
I/I	False output	0.01 / year	—	—	—	R-30
COOLING-TOWER FAN	Electric motor stops	0.5 / year	—	—	—	R-1
	Blade failure	0.02 / year	—	—	—	R-26
	Electric driver fails	0.02 / year	—	—	—	R-1
	Steam driver fails	0.003 / year	—	—	—	R-1
COUPLING, MECHANICAL	Fails to maintain coupling	0.006 / year	—	—	—	R-4

COMPONENT	FAILURE FREQUENCY (See Note 2) FAIL TO DANGER (See Note 3) Failure Mode	Frequency	FAIL TO SAFE (See Note 4) Failure Mode	Frequency	PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
CYLINDER, COMPRESSED GAS	Leak	See Note 11	—	—	—	—
	Rupture	See Note 11	—	—	—	—
DC ISOLATION MODULE	Fails to give output signal	0.01 / year	—	—	0.005 @1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-10
Driver, Electric or Steam	Fails to run	0.04 / yr				R-26
EXCHANGER, HEAT	See HEAT EXCHANGER					
EXPANSION JOINT, FLEX JOINT, METAL BELLOWS TYPE (Note 12) (CSA = Cross Sectional Area)	Small Leak (0.5-2% CSA)	0.12 / year	—	—	—	R-35
	Large Leak (5-20% CSA)	0.008 / year	—	—	—	R-35
	Rupture (50-100% CSA)	0.0005 / year	—	—	—	R-35
Fan, Cooling Tower (Driver not included)	Fails to Run	0.05 / year				R-26
FAN (i.e. e. EXHAUST FAN, INDUCED-DRAFT FAN, OR FORCED-DRAFT FAN) (Driver not included)	Fails to run	0.01 / year	—	—	—	R-1
	Fails to start	—	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-26
FILTER, PRESSURE	Treat as PRESSURE VESSEL, See Table E-10					
FINAL CONTROL ELEMENTS (See Note 13) (does not include solenoid valve for trip functions on air operated valves)						
DIAPHRAGM, RECIPROCATING (SPRING RETURN)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.04 / year	—	R-26
PISTON, RECIPROCATING (SPRING RETURN)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.05 / year	—	R-26

FINAL CONTROL ELEMENTS continued on following page

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
FINAL CONTROL ELEMENTS (continued)						
PISTON, RECIPROCATING (NO SPRING RETURN)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.05 / year	—	R-26
DIAPHRAGM, ROTARY (SPRING RETURN)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.05 / year	—	R-26
PISTON, ROTARY (SPRING RETURN)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.05 / year		R-26
PISTON, ROTARY (NO SPRING RETURN)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.05 / year	—	R-26
SOLENOID VALVE	Fails to de-energize or vent (de-energize to trip) or fails to energize (energize to trip)	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	De-energizes or vents prematurely	0.04 / year	—	R-26
TRIP AND THROTTLE VALVE (HYDRAULIC)	Fails in opposite direction to design	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in design direction	0.04 / year	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
FIRE DUE TO PUMP SEAL LEAK	See PUMP SEAL LEAK					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
FIRE DETECTOR:						
HEAT	Failure to detect initial fire	–	–	–	0.04 @ 1 yr 0.09 @ 2 yr 0.13 @ 3 yr	R-9
SMOKE	Failure to detect initial fire	–	–	–	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-9
SMOKE AND HEAT	Failure to detect initial fire	–	–	–	0.0005 @ 1 yr 0.001 @ 2 yr 0.002 @ 3 yr	R-9
UV OR IR	Failure to detect initial fire	–	–	–	0.15 @ 1 yr 0.30 @ 2 yr 0.45 @ 3 yr	R-9
FLAME SCANNER	Failure to detect flame	–	–	–	0.15 @ 1 yr 0.30 @ 2 yr 0.45 @ 3 yr	R-9
	Reports flame when no flame is present	–	–	–	0.015 @ 1 yr 0.03 @ 2 yr 0.045 @ 3 yr	R-26
FLAME ARRESTER, PLATE-TYPE	Failure to stop flame	–	–	–	0.03 @ 1 yr 0.06 @ 2 yr 0.09 @ 3 yr	R-16
FLANGES AND GASKETS						
FLAT TYPE (PER SET)	Leak (gasket hole)	0.002 / year	–	–	–	R-4
	Leak (total gasket failure)	0.0002 / year	–	–	–	R-24
SPIRAL WOUND TYPE WITH INNER AND OUTER RINGS (PER SET)	Leak (gasket hole)	0.001 / year	–	–	–	R-26
	Leak (total gasket failure)	0.0001 / year	–	–	–	R-26

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
FLEXIBLE BELLOWS	See EXPANSION JOINT					
FLEXIBLE HOSE	See HOSE, TRANSFER					
FLOW TRANSMITTER	See TRANSMITTER, FLOW					
FUSE	Fails to open	—	—	—	0.00001 @ 1 yr 0.00002 @ 2 yr 0.00003 @ 3 yr	R-10
	—	—	Opens prematurely	0.01 / year	—	R-10
GAS DETECTORS (LEL)	Fails to detect presence of flammable gas (from large gas leak)	—	—	—	See Note 14	R-16
	Fails to detect presence of flammable gas (from small gas leak)	—	—	—	See Note 15	R-16
GENERATOR (STANDBY):						
DIESEL OR GASOLINE	Fails to start	—	—	—	0.03 @ 1 yr 0.06 @ 2 yr 0.09 @ 3 yr	R-22
STEAM TURBINE	Fails to start	—	—	—	0.004 @ 1 yr 0.008 @ 2 yr 0.012 @ 3 yr	R-16
GLASS, SIGHT	See SIGHT GLASSES					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
HEAT EXCHANGER	Tube leak	0.04 / exchanger / year	—	—	—	R-26
	Tube rupture	0.01 / exchanger / year	—	—	—	R-26
	Shell leak	See Table E-10	—	—	—	—
	Shell rupture	See Table E-10	—	—	—	—
HEATER, ELECTRICAL	Fails to Heat	0.08 / year	—	—	—	R-25
	Overheats	0.01 / year	—	—	—	R-25
HOSE, TRANSFER, RUBBER, METAL, OR COMPOSITE (See Note 12)	Leaks	0.3 / year	—	—	—	R-5
	Ruptures	0.03 / year	—	—	—	R-5
INSTRUMENT IMPULSE LINE	Blocked	0.03 / year	—	—	—	R-22
	Leaks	0.07 / year	—	—	—	R-22
LEL DETECTOR	See GAS DETECTOR					
LEVEL TRANSMITTER	See TRANSMITTER, LEVEL					
LIFTING AND RIGGING ACTIVITY (See Note 16)	Drops 1-ton load	—	—	—	0.00005 / lift	R-22
	Swings and damages	—	—	—	0.0002 / lift	R-29
LIGHTNING (STRIKES PER SQUARE MILE PER YEAR)	See Note 17					
LOADING ARM	Ruptures	0.0003 / year	—	—	—	R-22
	Leaks	0.03 / year	—	—	—	R-22
LOAD CELL	Bad Reading	0.1 / year	—	—	0.05 @ 1 yr 0.1 @ 2 yr 0.15 @ 3 yr	R-26

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
MECHANICAL SEALS (ON PUMPS OR COMPRESSORS):						
SINGLE SEALS	Leaks	0.06 / year	–	–	–	R-31
DOUBLE SEALS	Leaks	0.03 / year	–	–	–	R-31
MOTOR, DIESEL	Stops	1.0 / year	–	–	–	R-26
	Fails to Start	–	–	–	0.03 @ 1 yr 0.06 @ 2 yr 0.09 @ 3 yr	R-22
MOTOR, ELECTRIC	Stops	0.04 / year	–	–	–	R-26
	Fails to Start or Stop	–	–	–	0.001 @ 1 yr 0.002 @ 2 yr 0.003 @ 3 yr	R-10
MOTOR MONITOR (for electric motors)	Fails to trip	0.01 / year	–	–	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	–	–	Premature Trip	0.025 / year	–	R-10
MOTOR, STARTER CONTACTOR	Fails to trip motor	0.012 / year	–	–	0.006 @ 1 yr 0.012 @ 2 yr 0.018 @ 3 yr	R-25
	Premature trip of motor	0.03 / year	–	–	–	R-25
MULTIPLEXER	Incorrect reading	0.01 / year	–	–	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	Fails to respond	0.01 / year	–	–	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
NOZZLE ON VESSEL	Leaks	0.001 / year	—	—	—	R-26
	Breaks off (See Note 18)	0.0001 / year	—	—	—	R-10
OVERSPEED TRIP, MECHANICAL	Fails to trip	0.04 / year	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-29
PIPE	See Table E-7					
PLC LOGIC (See Note 19)						
ALLEN-BRADLEY, INDUSTRIAL	Fails to trigger output	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	—	—	Triggers output prematurely	0.1 / year	—	R-26
MODICON	Fails to trigger output	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	—	—	Triggers output prematurely	0.1 / year	—	R-26
SIEMENS or TEXAS INSTRUMENTS	Fails to trigger output	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	—	—	Triggers output prematurely	0.1 / year	—	R-26
CERTIFIED FAULT TOLERANT SYSTEMS (e.g. Triconex Systems or Allen Bradley Safety PLC)	Fails to trigger output	See Note 20	—	—	See Note 20	R-26
	—	—	Triggers output prematurely	0.01/yr.	—	R-26
POWER MONITOR	See MOTOR MONITOR					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
POWER SUPPLY, AC	Plant-wide loss of power (based on plant experience)	See Note 21	–	–	–	–
	Local loss of power (due to fuse, switch, or wire break)	0.03 / year	–	–	–	R-10
POWER SUPPLY, DC	Fail to danger only if system is "energize to trip"	0.04 / year	Trips system (See Note 22)	0.04 / year	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-26
POWER SUPPLY, DCS (powering I/O device)	Loss of signal, fails in wrong direction	–	–	–	0.001 @ 1 yr 0.002 @ 2 yr 0.003 @ 3 yr	R-26
PRESSURE REGULATOR	See REGULATOR, PRESSURE					
PRESSURE RELIEF DEVICE (PRD)	See RELIEF VALVE					
PRESSURE SAFETY VALVE (PSV)	See RELIEF VALVE					
PRESSURE TRANSMITTER	See TRANSMITTER, PRESSURE					
PRESSURE VESSEL	See Table E-10					
PROCESS INTERLOCK (See Note 23)	Fails to trigger output	–	–	–	0.1 to 1.0	R-26
PUMP, CENTRIFUGAL						
ELECTRIC MOTOR DRIVEN (includes driver)	Fails to pump	0.3 / year	–	–	0.15 @ 1 yr 0.30 @ 2 yr 0.45 @ 3 yr	R-10
	Fails to start	–	–	–	0.003 @ 1 yr 0.006 @ 2 yr 0.009 @ 3 yr	R-10

PUMP, CENTRIFUGAL continued on following page

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
PUMP, CENTRIFUGAL (continued)						
STEAM TURBINE DRIVEN (includes driver)	Fails to pump	0.5 / year	—	—	0.25 @ 1 yr 0.50 @ 2 yr 0.75 @ 3 yr	R-10, R-16
	Fails to start	—	—	—	0.003 @ 1 yr 0.006 @ 2 yr 0.009 @ 3 yr	R-10
PUMP, DIAPHRAGM (PTFE)	Fails to pump due to diaphragm failure	0.85 / year	—	—	0.42 @ 1 yr 0.85 @ 2 yr 1.00 @ 3 yr	R-34
	Fails to start	—	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-25
PUMP SEAL LEAK:						
TEMP > AUTOIGNITION	Leak and fire (Note 24)	0.06 / pump / yr	—	—	—	R-31
TEMP > FLASH POINT	Leak and fire (Note 24)	0.0001 / pump / yr	—	—	—	R-6
TEMP < FLASH POINT	Leak and fire (Note 24)	0.00001 /pump/ yr	—	—	—	R-6
RAILCAR BUMPER POST (Prefabricated Steel):						
COLLISION WITH ONE CAR (100 TONS) ≥ 3 MPH	Failure to stop car	—	—	—	1.0	R-33
COLLISION WITH TWO CARS (200 TONS) ≥ 2 MPH	Failure to stop cars	—	—	—	1.0	R-33
COLLISION WITH THREE CARS (300 TONS) ≥ 1 MPH	Failure to stop cars	—	—	—	1.0	R-33

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
REGULATOR, PRESSURE	Fails to control pressure	0.05 / year	—	—	0.025 @ 1 yr 0.05 @ 2 yr 0.075 @ 3 yr	R-7
REGULATOR, TEMPERATURE BULB	Fails to control temperature	0.1 / year	—	—	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-7
RELAY LOGIC						
HEAVY DUTY (as required for SIS)	For De-Energize to Trip - Contacts fail closed – COMPANY STANDARD	0.002 / year	—	—	0.001 @ 1 yr 0.002 @ 2 yr 0.003 @ 3 yr	R-26
	For Energize to Trip – Contacts fail to close	0.004 / year			0.002 @ 1 yr 0.004 @ 2 yr 0.006 @ 3 yr	R-26
	—	—	Contacts fail open	0.004 / year		R-26
LIGHT DUTY or ICE CUBE STYLE (as used in Process Interlocks)	Contacts fail closed	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Contacts fail open	0.1 / year		R-26
TIME DELAY RELAY	Contacts fail closed	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Contacts fail open	0.04 / year	—	R-26

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
RELIEF VALVE (See Notes 25 and 26)	Fails to open	—	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	Premature opening (<90% of Set Pressure)	0.003 / year	—	—	—	R-7 R-29
	Premature opening (90-100% of Set Pressure)	0.015 / year	—	—	—	R-7 R-29
	Leaks through	0.05 / year	—	—	—	R-26
	Fails to re-seat after opening	—	—	—	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-37
RUPTURE DISK (See Notes 25 and 26)	Premature opening	0.02 / year	—	—	—	R-26
	Fails to burst	—	—	—	0.0002	R-26
SIGHT GLASS, WITH ARMORED GLASS (See Note 27)	Leaks	0.02 / year	—	—	—	R-26
	Glass breaks	0.001 / year	—	—	—	R-26
SIGHT GLASS, MAGNETIC	Leaks	0.006 / year	—	—	—	R-26
SPEED INDICATOR	See TACHOMETER					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
STEAM TRAP	Fails to dump condensate	0.1 / year	–	–	–	R-26
SWITCHES						
CURRENT	Fail to open contacts	0.01 / year	–	–	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	–	–	Contacts open with no demand	0.04 / year	–	R-26
FLOW (See Note 13)	Fail to open contacts	0.1 / year	–	–	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-26
	–	–	Contacts open with no demand	0.2 / year	–	R-26
LEVEL (FLOAT) (See Note 13)	Fail to open contacts	0.1 / year	–	–	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-26
	–	–	Contacts open with no demand	0.2 / year	–	R-26
LEVEL (SONIC) (See Note 13)	Fail to open contacts	0.025 / year	–	–	0.013 @ 1 yr 0.025 @ 2 yr 0.038 @ 3 yr	R-26
	–	–	Contacts open with no demand	0.05 / year	–	R-26
LEVEL (Vibrating Fork) (See Note 13)	Fail to open contacts	0.025 / year	–	–	0.013 @ 1 yr 0.025 @ 2 yr 0.038 @ 3 yr	R-26
	–	–	Contacts open with no demand	0.1 / year	–	R-26
LIMIT (MECHANICAL)	Fail to open contacts	0.1 / year	–	–	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-29

SWITCHES continued on following page

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
SWITCHES (continued)						
MANUAL (Heavy Duty Industrial on-off)	Fail to operate	0.004 / year	—	—	0.002 @ 1 yr 0.004 @ 2 yr 0.006 @ 3 yr	R-22
PUSH BUTTON (Heavy Duty Industrial)	Fail to operate	0.004 / year	—	—	0.002 @ 1 yr 0.004 @ 2 yr 0.006 @ 3 yr	R-22
PRESSURE (See Note 13)	Fail to open contacts	0.1 / year	—	—	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-26
	—	—	Contacts open with no demand	0.2 / year	—	R-26
PROXIMITY	Fail to open contacts	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	—	—	Contacts open with no demand	0.04 / year	—	R-26
TEMPERATURE	Fail to open contacts	0.1 / year	—	—	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-26
	—	—	Contacts open with no demand	0.2 / year	—	R-26
TACHOMETER	Fails to indicate speed	0.01 / year	—	—	—	R-26
TEMPERATURE BULB REGULATOR	See REGULATOR, TEMPERATURE BULB					
TEMPERATURE TRANSMITTER	See TRANSMITTER, TEMPERATURE					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
THERMOWELL, WELDED (CSA = Cross Sectional Area)	Small Leaks (0.5-2% CSA)	0.002 / year	—	—	—	R-35
	Large Leaks (5-20% CSA)	0.0002 / year	—	—	—	R-35
	Rupture (50-100% CSA)	0.00002 / year	—	—	—	R-35
TIMER, ELECTRIC (MECHANICAL)	Incorrect timing	0.05 / year	—	—	0.025 @ 1 yr 0.05 @ 2 yr 0.075 @ 3 yr	R-26
TIMER, ELECTRIC (SOLID STATE)	Incorrect timing	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
TMR LOGIC	See PLC LOGIC					
TRANSDUCER	See CONVERTER, SIGNAL					
TRANSMITTER, FLOW (See Note 13)						
HEAD TYPE	Incorrect reading or fails to respond	0.025 / year	—	—	0.013 @ 1 yr 0.025 @ 2 yr 0.038 @ 3 yr	R-26
	—	—	Fails in safe direction	0.05 / year	—	R-26
MAGNETIC	Incorrect reading or fails to respond	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
	—	—	Fails in safe direction	0.04 / year	—	R-26
MASS (CORIOLIS)	Incorrect reading or fails to respond	0.025 / year	—	—	0.013 @ 1 yr 0.025 @ 2 yr 0.038 @ 3 yr	R-26
	—	—	Fails in safe direction	0.07 / year	—	R-26

TRANSMITTER, FLOW continued on following page

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
TRANSMITTER, FLOW (continued)						
THERMAL	Incorrect reading or fails to respond	0.1 / year	—	—	0.05 @ 1 yr 0.10 @ 2 yr 0.15 @ 3 yr	R-39
	—	—	Fails in safe direction	0.2 / year	—	R-26
VORTEX	Incorrect reading or fails to respond	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in safe direction	0.1 / year	—	R-26
TRANSMITTER, LEVEL (See Note 13)						
CAPACITANCE OR CONDUCTANCE	Incorrect reading or fails to respond	0.04 / year	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-26
	—	—	Fails in safe direction	0.2 / year	—	R-26
d/P WITH REMOTE SEALS	Incorrect reading or fails to respond	0.04 / year	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-26
	—	—	Fails in safe direction	0.07 / year	—	R-26
d/P WITH DIAPHRAGM	Incorrect reading or fails to respond	0.04 / year	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-26
	—	—	Fails in safe direction	0.07 / year	—	R-26
HEAD TYPE, d/P	Incorrect reading or fails to respond	0.03 / year	—	—	0.015 @ 1 yr 0.03 @ 2 yr 0.045 @ 3 yr	R-26
	—	—	Fails in safe direction	0.1 / year	—	R-26
NUCLEAR	Incorrect reading or fails to respond	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-26
			Fails in safe direction	0.05 / year		

TRANSMITTER, LEVEL continued on following page

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
TRANSMITTER, LEVEL (continued)						
RADAR	Incorrect reading or fails to respond	0.03 / year	—	—	0.015 @ 1 yr 0.03 @ 2 yr 0.045 @ 3 yr	R-26
			Fails in safe direction	0.05 / year		
SONIC	Incorrect reading or fails to respond	0.04 / year	—	—	0.02 @ 1 yr 0.04 @ 2 yr 0.06 @ 3 yr	R-26
	—	—	Fails in safe direction	0.2 / year	—	R-26
TRANSMITTER, PRESSURE (See Note 13)						
PT DIRECT	Incorrect reading or fails to respond	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Fails in safe direction	0.025 / year	—	R-26
PT WITH DIAPHRAGM SEAL	Incorrect reading or fails to respond	0.03 / year	—	—	0.015 @ 1 yr 0.03 @ 2 yr 0.045 @ 3 yr	R-26
	—	—	Fails in safe direction	0.05 / year	—	R-26
TRANSMITTER, TEMPERATURE						
TE ELEMENT WITH TRANSMITTER	Incorrect reading or fails in a dangerous direction	0.025 / year	—	—	0.013 @ 1 yr 0.025 @ 2 yr 0.038 @ 3 yr	R-26
	—	—	Burnout failure in safe direction	0.05 / year	—	R-26
RTD ELEMENT WITH TRANSMITTER	Incorrect reading or fails in a dangerous direction	0.03 / year	—	—	0.015 @ 1 yr 0.03 @ 2 yr 0.045 @ 3 yr	R-26
	—	—	Burnout failure in safe direction	0.07 / year	—	R-26
TRICONEX SYSTEM	See PLC LOGIC					

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
TV SYSTEM, CLOSED CIRCUIT (See Note 28)	Fails to operate	0.4 / year	—	—	—	R-38
UPS HARDWARE (see note 30)	Fails to Transfer Power	0.003 / year	—	—	0.0015 @ 1 yr 0.003 @ 2 yr 0.0045 @ 3 yr	R-26
UPS BATTERY (per battery)	Fails to Supply Power	0.1 / year	—	—	See Note 30	R-26
VALVE, LEAKS						
Packing, External Leak	Small Leak	0.003 / year	—	—	—	R-10, R-16, R-18, R-35
Through, Internal Leak (CSA = Cross Sectional Area)	Small Leak (0.5 – 2% CSA)	0.01 / year	—	—	0.005 @ 1 yr 0.01 @ 2 yr 0.015 @ 3 yr	R-36
	Medium Leak (5 – 20% CSA)	0.001 / year	—	—	0.0005 @ 1 yr 0.001 @ 2 yr 0.0015 @ 3 yr	R-36
	Large Leak (50 – 100% CSA)	0.0002 / year	—	—	0.0001 @ 1 yr 0.0002 @ 2 yr 0.0003 @ 3 yr	R-36
VALVE, CHECK (See Note 26)	Reverse leak	0.02 / year	—	—	See Note 29	R-16
VALVE, CONTROL	See FINAL CONTROL ELEMENTS					
VALVE, EXCESS FLOW (See Note 26)	Fail to stop flow	0.3 — 0.003 / year	—	—	—	R-26
VALVE, RELIEF	See RELIEF VALVE					
VARIABLE SPEED CONTROLLER FOR MOTOR	Failure to drive motor	0.1 / year	—	—	—	R-25

COMPONENT	FAILURE FREQUENCY (See Note 2)				PFD (See Note 5) @ VARIOUS INSPECTION INTERVALS	REFERENCE (See Note 6)
	FAIL TO DANGER (See Note 3)		FAIL TO SAFE (See Note 4)			
	Failure Mode	Frequency	Failure Mode	Frequency		
VESSEL	See Table E-10					
VIBRATION MONITOR	Fails to detect vibration	0.1 / year	—	—	—	R-32
WATCHDOG TIMER CIRCUIT	Fails to detect logic stall	0.02 / year	—	—	0.01 @ 1 yr 0.02 @ 2 yr 0.03 @ 3 yr	R-26
	—	—	Circuit causes false trip	0.1 / year	—	R-26

Notes for Table E-1:

1. The omission of data (indicated by a dash "–") in some columns is intentional. There is either insufficient data to present, data is not applicable, or the data available is too questionable. Characterization of the failure frequencies or probabilities for these components requires assistance from a RA/RM Core Resource Person.

2. These failure frequencies do not include process-related failures. A process-related failure results from a process condition that could lead to a leak or rupture, i.e., an overpressure due to process reaction, over temperature due to failure to cool, etc. The leak frequencies in this table are due to mechanical failure only and do NOT include process-initiated leaks.

3. Some hardware devices have one *and only one* mode of failure; "fail to danger" for a device with only one failure mode simply means a failure can lead to an undesired event. However, most hardware devices have two modes of failure – high/low, on/off, open/closed, etc. "Fail to danger" for a device that has more than one failure mode means a failure in the *opposite* direction to the designer's intent – failing "high" when the device is supposed to fail "low", failing "open" when the device is supposed to fail "closed", and so on. Specific failure modes that lead to these conditions are listed for individual components.

4. "Fail to safe" for a device that has more than one failure mode means a failure in the *same* direction as the designer's intent – failing "high" when the device is supposed to fail "high", failing "open" when the device is supposed to fail "open", and so on. Most "fail to safe" failures will lead to a safe interruption of operation ("nuisance trip") for the associated component or process. Specific failure modes that lead to these conditions are listed for individual components where appropriate.

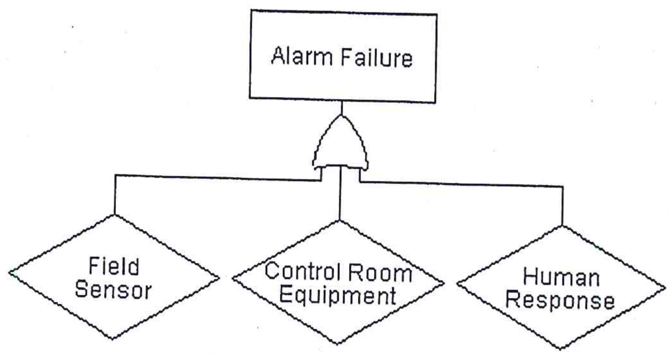
5. "Probability of Failure on Demand" (or PFD) is the likelihood that a component or a system will fail to perform its designated function at the time it is required (a demand is placed on it). PFDs are always dimensionless values between 0 and 1. The PFD value for a hardware device is highly dependent on inspection interval (the time between tests to confirm that the device is in working order). **PFD values are listed for one-year, two-year, and three-year inspection intervals**. The following equation can be used to find the PFD for other inspection intervals:

$$\begin{pmatrix}\text{PFD for inspection}\\ \text{interval} = \text{n years}\end{pmatrix} = (\text{PFD @ 1 year}) \times (\text{n, length of inspection interval in years})$$

If a component's inspection interval is greater than 3 years, the simple equation shown above cannot be used. Characterization of a PFD for a component with an inspection interval greater than 3 years requires assistance from a CRP; a second CRP should also review that characterization. With very frequent inspections, the time to inspect becomes significant and must be accounted for.

6. See attached reference list for source of data used in this table. Reference numbers are preceded by an R to distinguish them from note references in this table.

7. Alarm PFDs are dependent on the reliability of the field sensor, the control room equipment, and human response to the alarm. The logic is presented below:



Use Table E-1 to choose an appropriate PFD for "field sensor" based on the type of device installed (i.e. level transmitter, power monitor, etc.). For "control room enunciation equipment", use a PFD = 0.01 for DCS-based alarms, or a PFD = 0.03 for panel alarms (both values are based on an assumed annual inspection). The PFD for "human response" can be characterized using Table E-4. The analyst may need to include equipment operated in response to alarm, if complex, such as a stopper system. Part 10 and the Alarm Management SWP (PS-015-CEL) have additional guidance. More information can be found in Addendum N of SEP Part 10.

8. Probabilities of failure on demand (or PFDs) for most analyzers are strongly dependent not only on the length of time *between* inspections, but also on the length of time it takes to *perform* each inspection and/or calibration – assuming that the analyzer is taken "off-line" for the inspection, and that the process continues to operate while the analyzer is being inspected. The following special equations must be used to calculate PFD values for analyzers:

Type of Analyzer	Equation to Estimate PFD
Conductivity	$(0.035 \div N) + (0.0001 \times N \times L)$
Gas Chromatograph (GC)	$(0.5 \div N) + (0.0001 \times N \times L)$
Infrared (IR)	$(0.25 \div N) + (0.0001 \times N \times L)$
Oxygen	$(0.15 \div N) + (0.0001 \times N \times L)$
Stack Oxygen	$(0.035 \div N) + (0.0001 \times N \times L)$
N = number of inspections performed each year L = length of time to perform inspection (in hours)	

9. These failure frequencies are based on experience in ammonia plants with about 180 years of operating time. Lowest value is for gas circulators and highest is for refrigeration compressors.

10. The failure frequency for a DCS controller assumes a hot backup is provided for control processors. This value is for hardware only. To evaluate DCS thoroughly, both hardware and software must be analyzed. The reliability of software is a function of human error. The thoughts contained in Note 23 would be useful.

11. Based on information from the CGA (Compressed Gas Association) Internet Web Page, leaks and ruptures of gas cylinders are predominantly due to human actions. Leaks usually occur around the cylinder connections. Cylinder rupture usually occurs with mishandling of the cylinder, such as dropping the cylinder or putting the wrong chemical into the cylinder.

12. Failure data for "HOSES, TRANSFER" are for hoses used in loading, unloading, temporary installations, etc. These hoses are frequently moved or dragged across the ground. Failure frequencies for relatively short metallic "hoses" used as expansion joints or flex joints in stationary applications are best characterized using the data cited in Table E-1 under "EXPANSION JOINT, FLEX JOINT, METAL BELLOWS TYPE".

13. Failure frequencies for field-mounted instrument components are based on clean, non-plugging service. They should be adjusted to higher values based on experience in the application where they are installed. If no experience is available and plugging is expected, multiply the failure frequencies by a factor of 3 to 10 for moderate plugging and 10 to 100 for severe plugging potential.

14. PFDs for gas detectors (also referred to as LEL detectors) can be characterized using the same techniques used for analyzers (see Note 8). For gas detectors in the presence of a *large* leak of flammable material, calculate PFD using the following equation:

$$\text{PFD for Detection of } \textit{Large} \text{ Gas Leak} = 0.01 + (0.02 \div N) + (0.0001 \times N \times L)$$

where N = the number of inspections performed each year, and L = the length of time required to perform each inspection (measured in hours).

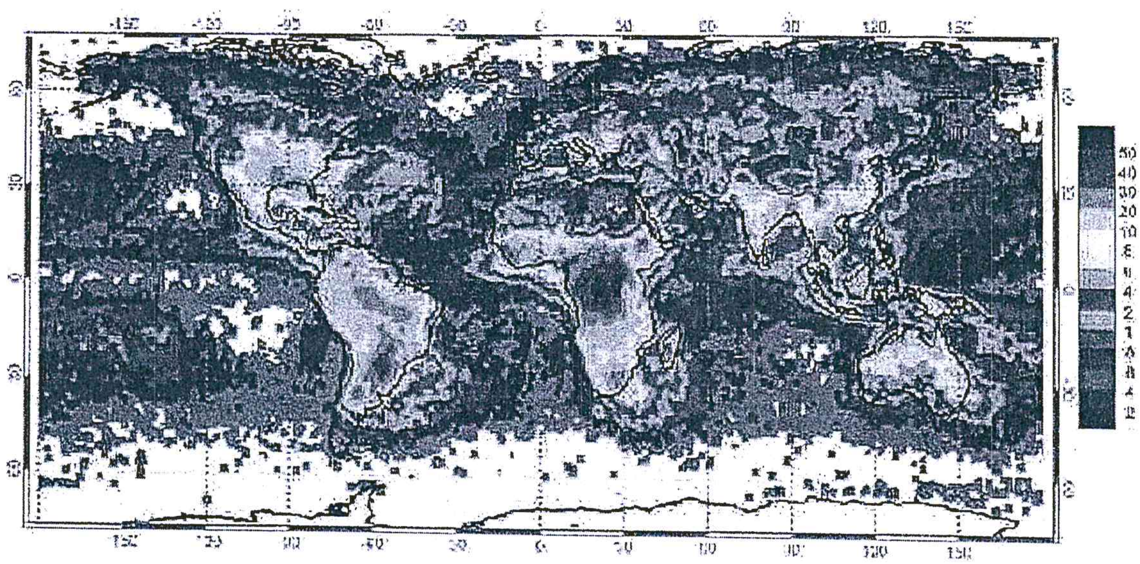
15. PFDs for gas detectors (also referred to as LEL detectors) can be characterized using the same techniques used for analyzers (see Note 8). For gas detectors in the presence of a *small* leak of flammable material, calculate PFD using the following equation:

$$\text{PFD for Detection of } \textit{Small} \text{ Gas Leak} = 0.1 + (0.02 \div N) + (0.0001 \times N \times L)$$

where N = the number of inspections performed each year, and L = the length of time required to perform each inspection (measured in hours).

16. For loads greater than 1 ton, assume the PFD is proportional to the size of the load. i.e., a 10-ton load would have a PFD for dropping of $10 \times 0.00005 = 0.0005$ / lift.

17. According to Fink and Beaty (R-3), the frequency of lightning strikes is commonly measured using the *ground flash density*, a quantity defined to be "the number of lightning strokes (cloud to ground) per unit area [per unit time]. It is preferable to use actual data for ground flash density, if available. If not, then as a first approximation, the ground flash density is taken to be approximately proportional to the thunderstorm activity, measured in thunderstorm days." A thunderstorm day is defined as a 24-hour period in which at least one thunderclap has been heard. Isokeraunic maps (showing lines of equal thunderstorm day activity) like the one below have been developed.



World map showing frequency of lightning strikes, in flashes per km² per year. Lightning strikes most frequently in the Democratic Republic of the Congo

On average, lightning strikes the earth about 100 times every second. "Lightning Alley", referring to Interstate 4 between Orlando and St. Petersburg FL, collectively sees more lightning strikes per year than any other place in the US. "Lightning Alley" averages 120 thunderstorm days per year. The Empire State Building is struck by lightning on average 23 times each year, and was once struck 8 times in 24 minutes.

Singapore has one of the highest rates of lightning activity in the world. The city of Teresina in northern Brazil has the third-highest rate of occurrences of lightning strikes in the world. The surrounding region is referred to as the Chapada do Corisco ("Flash Lightning Flatlands").

18. Adjust failure frequency upward to account for outside influences such as external corrosion, using nozzle as step ladder, heavy equipment loads on nozzle, etc.

19. The manufacturers listed are those included in the Approved Manufacturers List contained within Celanese SEP Instrumentation Section, Part 10.

20. Failure frequencies for fault tolerant / safety PLC logic systems (IEC 61508 compliant) are strongly dependent on application specifics (i.e. I/O loading). Probabilities of failure on demand for those same systems demonstrate a non-linear relationship with inspection interval. As a result, failure frequencies and PFDs for these devices must be obtained from the manufacturer or from third-party certifying agencies. Documentation of the PFD values determined by manufacturers and certifying agencies should be maintained in the SIS manual. The equipment must be certified for your application, e.g. de-energize to trip or energize to trip. Talk to a CRP for clarification. The largest certifying agency is the *Technisher Uberwachungs-Verein* (or *TUV*), a German organization that has been authorized to inspect and certify safety systems since 1872. The *TUV* is made up of many divisions, but two organizations – *TUV* Rheinland and *TUV* Product Services – certify safety systems for compliance against standards. Another organization that certifies safety systems is Factory Mutual Research, a non-profit research and testing organization managed by FM Global.

21. Local experience in total electrical outages should be used whenever this is a factor in the analysis. Based on Celanese experience at a number of locations, complete, long duration outages could occur as often as several times a year or as infrequently as once every 30 years or more.

22. Power loss is assumed to initiate a system shutdown that is safe. If "energize to trip" systems are installed, consult an RA/RM Core Resource Person.

23. The range of allowable PFD values for process interlocks is 0.1 to 1.0. If the process interlock is documented, initial functional testing has been performed, effective management of change has been in place since the last functional test, and field instrumentation is periodically inspected on an established schedule, then a PFD of 0.5 can be used. If the above minimum criteria have not been met, then no credit can be taken and a PFD of 1.0 must be used.

    To use a PFD lower than 0.5, follow the detailed instructions in Celanese SEP Part 10, Addendum D.. Use the checklist located in Addendum D of Part 10 to calculate PFD and document that activity. A CRP should be consulted for assistance.

24. The failure frequency for pump seals resulting in fires includes the frequency for the initial seal leak. These frequencies are for single seals. For basic mechanical seal leak frequencies, see "Mechanical Seals" in Table E-1.

25. A discharge from a relief valve or rupture disk is required to be safe per company

standards.

26. Failure of these components is highly dependent on fluid properties. Fluids that are dirty, viscous, or have plugging potential require the use of higher failure frequency numbers.

27. Failures are for one section of sight glass (normally 14" long) or for one typical glass view-port (or "bulls-eye"). Glass components are assumed to have been selected and installed in accordance with Celanese SEP Instrumentation Section, Part 3 for Level Devices.

28. The failure frequency value cited for closed circuit TV is for the entire system – including camera, monitor, and any associated wiring.

29. PFDs for check valves must be calculated using specific knowledge of the inspection interval, which varies widely from one application to another:

For Check Valves ONLY: $\mathrm{PFD} = 0.01\ /\mathrm{yr} \times \mathrm{TI}$

where TI is the interval between inspections of the check valve, in years.

30. The value for "BATTERY" cited in Table E-1 is for a single battery. If there is a requirement to have multiple batteries in a bank to supply the power needs of the system, then the failure data would need to be multiplied by the number of batteries required.

The failure frequency cited is for a 10 year life battery. If that battery is replaced earlier, then additional credit can be taken as follows:

For Batteries ONLY: $f = 0.1 / yr \times 1 / RI$

where RI is the interval between replacement of the batteries, in years.

It is typical to inspect batteries very frequently, to calculate the PFD, use the following equation:

For Batteries ONLY: $PFD = 0.015 /yr \times TI$

where TI is the interval between inspections of the batteries, in years.

Example: If 10 year batteries are replaced every 3 years and inspected monthly, then the PFD would be 0.00125 after executing the two equations above for RI = 3 and TI = 1/12.