EQUIPMENT FAILURE AND HUMAN ERROR RATES

Additional Risk Assessment Data

Table B-I gives estimates of cryogenic equipment failure rates. These data are median estimates collected from past ODH risk assessments performed on systems at Fermilab. This data has been updated to include the revised failure rate estimates as described by B. Soyars (Fermilab) report, " Appendix: Rationale for Table 1 – Fermilab Equipment Failure Rate Estimates," dated January 26, 2000. Table B-II shows failure rates for various equipment types derived from the nuclear power industry that may be useful as input data (MOV – Manually operated valves/SOV - Solenoid operated valves/AOV – Automatically operated valves). General human error rate estimates are presented in Table B-III. Table B-IV lists conservative estimates of the rate of human error as a function of task type and time limit.

TABLE B-I
FERMILAB EQUIPMENT FAILURE RATE ESTIMATES

Component	Failure Mode	Estimated Median Failure Rate
Compressor (Cryogenic)	Leak Rupture	5×10^{-6}/HR 3×10^{-7}/HR
Dewar	Leak or Rupture	1×10^{-6}/HR
Electrical Power Failure (unplanned)	Time Rate Demand Rate Time Off	1×10^{-4}/HR 3×10^{-4}/Demand 1 HR
Fluid Line (Cryogenic)	Leak Rupture	5×10^{-7}/HR 2×10^{-8}/HR
Magnet (Cryogenic, Powered, unmanned)	Leak or Rupture	2×10^{-7}/HR
Magnet (Cryogenic, Not Powered, unmanned)	Leak or Rupture	2×10^{-8}/HR
Header Piping Assembly	Rupture	1×10^{-8}/HR
Change of Equipment with Bayonet Fitting (Cryogenic Release)	Small Event Large Event	3×10^{-2}/Demand 1×10^{-3}/Demand

TABLE B-II U.S. NRC EQUIPMENT FAILURE RATE ESTIMATES		
COMPONENT	FAILURE MODE	FAILURE RATE
Battery Power Supplies	No Output	$3x10^{-6}$/hr
Circuit Breakers	Failure to Operate	$1x10^{-3}$/demand
	Premature Transfer	$1x10^{-6}$/hr
Diesel (Complete Plant)	Failure to Start	$3x10^{-2}$/demand
	Fails to Run (Emergency loads)	$3x10^{-3}$/hr
	Fails to Run (Engine Only)	$3x10^{-4}$/hr
Electric Motors	Failure to Start	$3x10^{-4}$/demand
	Fails to Run	$1x10^{-5}$/hr
	Fails to Run (Extreme Environment)	$1x10^{-3}$/hr
Fuses	Premature Open	$1x10^{-6}$/hr
	Failure to Open	$1x10^{-5}$/demand
Gaskets	Leak	$3x10^{-6}$/hr
Flanges/Closures/Elbows	Leak/Rupture	$3x10^{-7}$/hr
Instrumentation (Amplification, Annunciators, Transducers, Calibration, Combination)	Failure to Operate	$1x10^{-6}$/hr
	Shifts	$3x10^{-5}$/hr
Pipes >3" (High Quality)	Rupture (section)	$1x10^{-10}$/hr
Pipes <3" (High Quality)	Rupture	$1x10^{-9}$/hr
Pumps	Failure to Start	$1x10^{-3}$/demand
	Fails to Run	$3x10^{-5}$/hr
	Fails to Run (Extreme Environment)	$1x10^{-3}$/hr
Relays	Failure to Energize	$1x10^{-4}$/demand
	Failure NO Contact to Close	$3x10^{-7}$/hr
	Short Across NO/NO Contacts	$1x10^{-8}$/hr
	Open NC Contact	$1x10^{-7}$/hr
Solid State Devices (High Power Applications)	Failure to Function	$3x10^{-6}$/hr
	Shorts	$1x10^{-6}$/hr
Solid State Devices (Low Power Applications)	Failure to Function	$1x10^{-6}$/hr
	Shorts	$1x10^{-7}$/hr
Transformers	Open	$1x10^{-6}$/hr
	Short	$1x10^{-6}$/hr
Switches	Limit - Fails to Operate	$3x10^{-4}$/demand
	Torque - Fails to Operate	$1x10^{-4}$/demand
	Pressure - Fails to Operate	$1x10^{-4}$/demand
	Manual - Fails to Transition	$1x10^{-5}$/demand
	Manual – Contact Shorts	$1x10^{-8}$/hr
Valves: MOV	Fails to Operate	$1x10^{-3}$/demand
	Fails to Remain Open (plug)	$1x10^{-4}$/demand
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: SOV	Fails to Operate	$1x10^{-3}$/demand
Valves: AOV	Fails to Operate	$3x10^{-4}$/demand
	Fails to Remain Open (plug)	$1x10^{-4}$/demand
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: Check	Fails to Operate	$1x10^{-4}$/demand
	Reverse Leak	$3x10^{-7}$/hr
	External Leak – Rupture	$1x10^{-8}$/hr
Valves: Vacuum	Fails to Operate	$3x10^{-5}$/demand
	Rupture	$1x10^{-8}$/hr
Valves: Orifices, Flow Meters	Rupture	$1x10^{-8}$/hr

TABLE B-II U.S. NRC EQUIPMENT FAILURE RATE ESTIMATES		
COMPONENT	FAILURE MODE	FAILURE RATE
Valves: Manual	Fails to Remain Open (plug)	$1x10^{-4}$/demand
Valves: Relief	Fails to Open	$1x10^{-5}$/demand
	Premature Open	$1x10^{-5}$/hr
Welds	Leaks	$3x10^{-9}$/hr
Wires	Open	$3x10^{-6}$/hr
	Short to Ground	$1x10^{-7}$/hr
	Short to Power	$1x10^{-8}$/hr

TABLE B-III HUMAN ERROR RATE ESTIMATES	
Estimated Error Rate (Demand^{-1})	Activity
10^{-3}	Selection of a switch (or pair of switches) dissimilar in shape or location to the desired switch (or pair of switches), assuming no decision error. For example, operator actuates large handled switch rather than small switch.
3×10^{-3}	General human error of commission, e.g., misreading label and therefore selecting wrong switch.
10^{-2}	General human error of omission where there is no display in the control room of the status of the item omitted, e.g., failure to return manually operated test valve to proper configuration after maintenance.
3×10^{-3}	Errors of omission, where the items being omitted are embedded in a procedure rather than at the end as above.
1/x	Given that an operator is reaching for an incorrect switch (or pair of switches), he selects a particular similar appearing switch (or pair of switches), where x = the number of incorrect switches (or pair of switches) adjacent to the desired switch (or pair of switches). The 1/x applies up to 5 or 6 items. After that point, the error rate would be lower because the operator would take more time to search. With up to 5 or 6 items he doesn't expect to be wrong and therefore is more likely to do less deliberate searching.
10^{-1}	Monitor or inspector fails to recognize initial error by operator. Note: With continuing feedback of the error on the annunciator panel, the high error rate would not apply.
10^{-1}	Personnel on different work shift fail to check condition of hardware unless required by check or written directive.
5×10^{-1}	Monitor fails to detect undesired position of valves, etc., during general walk-around inspection, assuming no check list is used.
.2 - .3	General error rate given very high stress levels where dangerous activities are occurring rapidly.
$2^{(n-1)}x$	Given severe time stress, as in trying to compensate for an error made in an emergency situation, the initial error rate, x, for an activity doubles for each attempt, n, after a previous incorrect attempt, until the limiting condition of an error rate of 1.0 is reached or until time runs out. This limiting condition corresponds to an individual's becoming completely disorganized or ineffective.

TABLE B-IV
HUMAN ERROR RATE AS A FUNCTION OF RESPONSE TIME

	Response Time in Seconds		
Maximum Estimated Error Rate (Demand^{-1})	Skill Based Task	Rule Based Task	Knowledge Based Task
10^{-4}	37	600	18,000
10^{-3}	26	300	10,000
10^{-2}	16	130	4,900
10^{-1}	8.7	42	1,800
5×10^{-1}	4.0	10	550

Skill-Based Task – An individual initiates a single-step, learned response upon receipt of an unambiguous sensor cue (i.e., a lone worker initiates escape upon hearing an oxygen deficiency alarm).

Rule-Based Task – An individual or small group of individuals diagnoses and initiates corrective actions for a simple problem given limited or ambiguous input (i.e., several workers decide whether or not to escape given that one of them passes out but no oxygen deficiency alarms sound).

Knowledge-Based Task - A group of individuals diagnoses and initiates corrective actions for novel and/or complex problem.