7

APPENDIX B

Failure Data

Table B-1 *Hazard Rates λ and Demand Failure Probabilities Q_d for Mechanical Hardware*[a,b]

Components	Failure mode	Assessed range on probability of occurrence	Computational median	Error factor
1. Pumps				
(includes	Failure to start on demand Q_d[c]	$3 \times 10^{-4} - 3 \times 10^{-3}$/d	1×10^{-3}/d	3
driver)	Failure to run, given start λ_0 (normal environments)	$3 \times 10^{-6} - 3 \times 10^{-4}$/hr	3×10^{-5}/hr	10
	Failure to run, given start λ_0 (extreme, post-accident environments inside containment)	$1 \times 10^{-4} - 1 \times 10^{-2}$/hr	1×10^{-3}/hr	10
	Failure to run, given start λ_0 (post-accident, after environmental recovery)	$3 \times 10^{-5} - 3 \times 10^{-3}$/hr	3×10^{-4}/hr	10
2. Valves				
a. Motor operated:	Failure to operate (includes driver) Q_d[d]	$3 \times 10^{-4} - 3 \times 10^{-3}$/d	1×10^{-3}/d	3
	Failure[e] to remain open (plug) Q_d	$3 \times 10^{-5} - 3 \times 10^{-4}$/d	1×10^{-4}/d	3
	λ_s	$1 \times 10^{-7} - 1 \times 10^{-6}$/hr	3×10^{-7}/hr	3
	Rupture λ_s	$1 \times 10^{-9} - 1 \times 10^{-7}$/hr	1×10^{-8}/hr	10
b. Solenoid operated:	Failure to operate Q_d	$3 \times 10^{-4} - 3 \times 10^{-3}$/d	1×10^{-3}/d	3
	Failure to remain open, Q_d (plug)	$3 \times 10^{-5} - 3 \times 10^{-4}$/d	1×10^{-4}/d	3
	Rupture λ_s	$1 \times 10^{-9} - 1 \times 10^{-7}$/hr	1×10^{-8}/hr	10
c. Air-fluid operated:	Failure to operate Q_d	$1 \times 10^{-4} - 1 \times 10^{-3}$/d	3×10^{-4}/d	3
	Failure to remain open Q_d (plug)	$3 \times 10^{-5} - 3 \times 10^{-4}$/d	1×10^{-4}/d	3
	λ_s	$1 \times 10^{-7} - 1 \times 10^{-6}$/hr	3×10^{-7}/hr	3
	Rupture λ_s	$1 \times 10^{-9} - 1 \times 10^{-7}$/hr	1×10^{-8}/hr	10
3. Check valves	Failure to open Q_d	$3 \times 10^{-5} - 3 \times 10^{-4}$/d	1×10^{-4}/d	3
	Internal leak λ_s (severe)	$1 \times 10^{-7} - 1 \times 10^{-6}$/hr	3×10^{-7}/hr	3
	Rupture λ_s	$1 \times 10^{-9} - 1 \times 10^{-7}$/hr	1×10^{-8}/hr	10
4. Vacuum valve	Failure to operate Q_d	$1 \times 10^{-5} - 1 \times 10^{-4}$/d	3×10^{-5}/d	3
5. Manual valve	Failure to remain open Q_d (plug)	$3 \times 10^{-5} - 3 \times 10^{-4}$/d	1×10^{-4}/d	3
	Rupture λ_s	$1 \times 10^{-9} - 1 \times 10^{-7}$/hr	1×10^{-8}/hr	10
6. Relief valves	Failure to open Q_d	$3 \times 10^{-6} - 3 \times 10^{-5}$/d	1×10^{-5}/d	3
	Premature open λ_s	$3 \times 10^{-6} - 3 \times 10^{-5}$/hr	1×10^{-5}/hr	3
7. Test valves, flow meters, orifices	Failure to remain open Q_d (plug)	$1 \times 10^{-4} - 1 \times 10^{-3}$/d	3×10^{-4}/d	3
	Rupture λ_s	$1 \times 10^{-9} - 1 \times 10^{-7}$/hr	1×10^{-8}/hr	10
8. *Pipes*				
a. Pipe $\leq$ 7.5 cm diam per section	Rupture/plug λ_s, λ_s	$3 \times 10^{-11} - 3 \times 10^{-8}$/hr	1×10^{-9}/hr	30

(Continued)

Table B-1 (*Continued*)

Components	Failure mode	Assessed range on probability of occurrence	Computational median	Error factor
b. Pipe > 7.5 cm diam per section	Rupture λ_s, λ_o	3×10^{-12}–3×10^{-9}/hr	1×10^{-10}/hr	30
9. Clutch, mechanical	Failure to operate Q_d	1×10^{-4} –1×10^{-3}/d	3×10^{-4}/d	3
10. Scram rods (single)	Failure to insert	3×10^{-5} -3×10^{-4}/d	1×10^{-4}/d	3

[a] From *Reactor Safety Study*, Appendix III, Failure Data, WASH-1400, October 1975.
[b] See Section 5·3 for discussion of use.
[c] Demand probabilities are based on the presence of proper input control signals. For turbine driven pumps, the effect of failures of valves, sensors, and other auxiliary hardware may result in significantly higher overall failure rates for turbine driven pump systems.
[d] Demand probabilities are based on presence of proper input control signals.
[e] Plug probabilities are given in demand probability, and per hour rates, since phenomena are generally time dependent, but plugged condition may only be detected upon a demand of the system.

Table B-2 *Hazard Rates λ and Demand Failure Probabilities Q_d for Electrical Equipment*[a,b]

Component	Failure mode	Assessed range	Computational median	Error factor
1. Clutch, electrical	Failure to operate Q_d[c]	1×10^{-4}–1×10^{-3}/d	3×10^{-4}/d	3
	Premature disengagement λ_o	1×10^{-7}–1×10^{-5}/hr	1×10^{-6}/hr	10
2. Motors, electric	Failure to start Q_d	1×10^{-4}–1×10^{-3}/d	3×10^{-4}/d	3
	Failure to run, given start λ_o (normal environment)	3×10^{-6}–3×10^{-5}/hr	1×10^{-5}/hr	3
	Failure to run, given start λ_o (extreme environment)	1×10^{-4}–1×10^{-2}/hr	1×10^{-3}/hr	10
3. Relays	Failure to energize Q_d	3×10^{-5}–3×10^{-4}/d	1×10^{-4}/d	3
	Failure of NO contacts to close, given energized λ_o	1×10^{-7}–1×10^{-6}/hr	3×10^{-7}/hr	3
	Failure of NC contacts by opening, given not energized λ_o	3×10^{-8}–3×10^{-7}/hr	1×10^{-7}/hr	3
	Short across NO/NC contact λ_o	1×10^{-9}–1×10^{-7}/hr	1×10^{-8}/hr	10
	Coil open λ_o	1×10^{-8}–1×10^{-6}/hr	1×10^{-7}/hr	10
	Coil short to power λ_o	1×10^{-9}–1×10^{-7}/hr	1×10^{-8}/hr	10
4. Circuit breakers	Failure to transfer Q_d	3×10^{-4}–3×10^{-3}/d	1×10^{-3}/d	3
	Premature transfer λ_o	3×10^{-7}–3×10^{-6}/hr	1×10^{-6}/hr	3
5. Switches				
a. Limit	Failure to operate Q_d	1×10^{-4}–1×10^{-3}/d	3×10^{-4}/d	3
b. Torque	Failure to operate Q_d	3×10^{-5}–3×10^{-4}/d	1×10^{-4}/d	3
c. Pressure	Failure to operate Q_d	3×10^{-5}–3×10^{-4}/d	1×10^{-4}/d	3
d. Manual	Failure to transfer Q_d	3×10^{-6}–3×10^{-5}/d	1×10^{-5}/d	3

Table B-2 (*Continued*)

Component	Failure mode	Assessed range	Computational median	Error factor
6. Switch contacts	Failure of NO contacts to close given switch operation λ_0	1×10^{-8}–1×10^{-6}/hr	1×10^{-7}/hr	10
	Failure of NC by opening, given no switch operation λ_0	3×10^{-9}–3×10^{-7}/hr	3×10^{-8}/hr	10
	Short across NO/NC contact λ_0	1×10^{-9}–1×10^{-7}/hr	1×10^{-8}/hr	10
7. Battery power systems (wet cell)	Failure to provide proper output λ_s	1×10^{-6}–1×10^{-5}/hr	3×10^{-6}/hr	3
8. Transformers	Open circuit primary or secondary λ_0	3×10^{-7}–3×10^{-6}/hr	1×10^{-6}/hr	3
	Short primary to secondary λ_0	3×10^{-7}–3×10^{-6}/hr	1×10^{-6}/hr	3
9a. Solid state devices hi power applications (diodes, transistors, etc.)	Fails to function λ_0	3×10^{-7}–3×10^{-5}/hr	3×10^{-6}/hr	10
	Fails shorted λ_0	1×10^{-7}–1×10^{-5}/hr	1×10^{-6}/hr	10
b. Solid state devices, low power applications	Fails to function λ_0	1×10^{-7}–1×10^{-5}/hr	1×10^{-6}/hr	10
	Fails shorted	1×10^{-8}–1×10^{-6}/hr	1×10^{-7}/hr	10
10a. Diesels (complete plant)	Failure to start Q_d	1×10^{-2}–1×10^{-1}/d	3×10^{-2}/d	3
	Failure to run, emergency conditions, given start λ_0	3×10^{-4}–3×10^{-2}/hr	3×10^{-3}/hr	10
b. Diesels (engine only)	Failure to run, emergency conditions, given start λ_0	3×10^{-5}–3×10^{-3}/hr	3×10^{-4}/hr	10
11. Instrumentation—general (includes transmitter, amplifier, and output device)	Failure to operate λ_0	1×10^{-7}–1×10^{-5}/hr	1×10^{-6}/hr	10
	Shift in calibration λ_0	3×10^{-6}–3×10^{-4}/hr	3×10^{-5}/hr	10
12. Fuses	Failure to open Q_d	3×10^{-6}–3×10^{-5}/d	1×10^{-5}/d	3
	Premature open λ_0	3×10^{-7}–3×10^{-6}/hr	1×10^{-6}/hr	3
13. Wires (typical circuits, several joints)	Open circuit λ_0	1×10^{-6}–1×10^{-5}/hr	3×10^{-6}/hr	3
	Short, to ground λ_0	3×10^{-8}–3×10^{-6}/hr	3×10^{-7}/hr	10
	Short to power λ_0	1×10^{-9}–1×10^{-7}/hr	1×10^{-8}/hr	10
14. Terminal boards	Open connection λ_0	1×10^{-8}–1×10^{-6}/hr	1×10^{-7}/hr	10
	Short to adjacent circuit λ_0	1×10^{-9}–1×10^{-7}/hr	1×10^{-8}/hr	10

[a] From *Reactor Safety Study*, Appendix III, Failure Data, WASH-1400, October 1975.
[b] See Section 5-3 for discussion of use.
[c] Demand probabilities are based on presence of proper input control signals.

Table B-3 *Human Error Probabilities*[a,b]

Demand failure probability	Activity
10^{-4}	Selection of a key-operated switch rather than a nonkey switch. (This value does not include the error of decision where the operator misinterprets situation and believes key switch is correct choice.)
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 when 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.
3×10^{-2}	Simple arithmetic errors with self-checking but without repeating the calculation by redoing it on another piece of paper.
$1/x$	Given that an operator is reaching for an incorrect switch (or pair of switches), he or she selects a particular similar appearing switch (or pair of switches), where $x =$ the number of incorrect switches (or pairs 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, the operator doesn't expect to be wrong and therefore is more likely to do less deliberate searching.
10^{-1}	Given that an operator is reaching for a wrong motor operated valve MOV switch (or pair of switches), he or she fails to note from the indicator lamps that the MOV(s) is (are) already in the desired state and merely changes the status of the MOV(s) without recognizing that he or she had selected the wrong switch(es).
~ 1.0	Same as above, except that the state(s) of the incorrect switch(es) is (are) *not* the desired state.
~ 1.0	If an operator fails to operate correctly one of two closely coupled valves or switches in a procedural step, he or she also fails to correctly operate the other valve.
10^{-1}	Monitor or inspector fails to recognize initial error by operator. Note: With continuing feedback of the error on the annunciator panel, this high error rate would not apply.
10^{-1}	Personnel on different work shift fail to check condition of hardware unless required by checklist or written directive.

Table B-3 (*Continued*)

Demand failure probability	Activity
5×10^{-1}	Monitor fails to detect undesired position of valves, etc., during general walk-around inspections, assuming no check list is used.
0.2–0.3	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.
~1.0	Operator fails to act correctly in the first 60 seconds after the onset of an extremely high stress condition, e.g., a large LOCA.
9×10^{-1}	Operator fails to act correctly after the first 5 minutes after the onset of an extremely high stress condition.
10^{-1}	Operator fails to act correctly after the first 30 minutes in an extreme stress condition.
10^{-2}	Operator fails to act correctly after the first several hours in a high stress condition.
x	After 7 days after a large LOCA, there is a complete recovery to the normal error rate x, for any task.

[a] Reactor Safety Study, Appendix III, Failure Data, WASH-1400 (October 1975).

[b] See Section 5-4 for discussion of use.