DFMEA														
Ref ID	Block	Item	Failure Mode	Local effect	2nd level effect	3rd level effect	Severity (1-10)	Potential Cause(s)	Occurrence (1-10)	Detection	Detection (1-10)	RPN (S x O x D)	Current Process Control(s)	Recommended Action(s)	Action Priority
Heater Bed Assy															
1.1.1	Heated Bed	Silicone Heater	Short circuit	Lowered heating element resistance	Unexpected temperature rise for a given power input	Fire risk	10	Manufacturing defect; Component damage	1	Thermal fuse; Current fuse; Thermistor + SW control loop	2	20	Thermal fuse; Current fuse; Thermistor + SW control loop	None	L
1.1.2	Heated Bed	Silicone Heater	Open circuit mains wire	No power input to heater	System fails to reach desired temperature	-	2	Motion fatigue; Improper strain relief; Caught in motion system	4	Thermistor + SW control loop	2	16	Thermistor + SW control loop	None	L
1.1.3	Heated Bed	Silicone Heater	Open circuit NTC thermistor wire	Thermistor resistance increases to infinity	Controller interprets temperature lower than actual	-	3	Motion fatigue; Improper strain relief; Caught in motion system	4	SW control loop	2	24	SW control loop	Research heaters with PTC thermistors	L
1.1.4	Heated Bed	Silicone Heater	Short circuit NTC thermistor wire	Thermistor resistance decreases to zero	Controller interprets temperature higher than actual	-	1	Motion fatigue; Improper strain relief; Caught in motion system	1	SW control loop	2	2	SW control loop	None	L
1.1.5	Heated Bed	Silicone Heater	Mains wire insulation breakdown	Exposed mains voltage	Electric shock risk	-	7	Motion fatigue; Mechanical damage	3	Visual	7	147	Grounded metal chassis	Use motion rated wire	M
1.1.6	Heated Bed	Silicone Heater	Loose mains wire connection	Increased electrical resistance	Overheating at wire junction	-	6	Vibration; Exposure to high temperature on connector; Corrosion	2	Manual via thermal imager; Thermal fuse; Current fuse;	3	36	Use of vibration and high temp rated connectors	Ensure connector are temp and vibration rated	L
1.1.7	Heated Bed	Silicone Heater	Adhesive failure	Reduced thermal transfer to aluminum bed	Hotspot forms around air pocket	Heater sags and falls off of aluminum bed	8	Improper application; max operating temperature exceeded	1	Visual	5	40	High temp rated adhesive	Add insulated metal backing sandwich to bed heater	L
1.2.1	Heated Bed	Aluminum Plate	Broken AC ground connection	Exposed metal surface with floating electrical potential	Electric shock risk	-	7	Motion fatigue; Improper strain relief; Caught in motion system	2	Visual	7	98	None	????	M
1.3.1	Heated Bed	SSR	Stuck closed	Relay output can no longer be switched off	Power continues to flow to heater	Fire risk	10	Damage from overcurrent or large inrush; Hardware failure; Controller lockup	2	Thermal fuse on heater; Thermal fuse on SSR; Current fuse; Thermistor on heater + SW control loop	2	40	Thermal fuse on heater; Thermal fuse on SSR; Current fuse; Thermistor on heater + SW control loop	None	L
1.3.2	Heated Bed	SSR	Stuck open	Relay output can no longer be switch on	Bed heater does not receive power	-	1	Hardware failure; Upstream component damage	1	Thermistor on heater + SW control loop	1	1	Themistor on heater + SW control loop	None	L
1.3.3	Heated Bed	SSR	Overheating	Thermal de-rating	Temperature rise	Fire risk	10	Improperly specced heatsink; Overcurrent	3	Thermal fuse on SSR	2	60	Thermal fuse on SSR; adequate heatsink for load current and ambient temperature	None	L
1.4.1	Heated Bed	Contactor	Stuck closed	Contacts welded together	Controller unable to switch contactor off	Power continues to flow downstream	6	Damage from overcurrent; Frequent cycling with large loads applied; Controller lockup	1	Visual	7	42	Switch off SSR before switching off contactor & vice versa to minimize spark	Switch off SSR before switching off contactor & vice versa to minimize spark	L
1.5.1	Heated Bed	MCU	Controller failure with outputs high	Contactor outputs stay closed; SSRs switch on with 100% duty cycle	Power continues to flow to heater	Fire risk	10	Software bug; Hardware failure / mosfet fused closed; Damage from reverse voltage spike on contactor release	2	Thermal fuse on bed heater; Thermal fuse on bed SSR; Current fuse on bed SSR; Thermistor on heater + SW control loop; Klipper/moonraker timeout on RPI	1	20	Moonraker control loop + mains relay	None	L
1.5.2	Heated Bed	MCU	Controller failure with outputs low	Contactor outputs release; SSR switches off	Heater does not receive power	-	1	Software bug; Hardware failure	1	Klipper/moonraker timeout on RPI	3	3	Moonraker control loop + mains relay	None	L
1.6.1	Heated Bed	RPi	Controller failure/restart with GPIO high	Mains relay stays closed; printer continues to operate	MCU times out	-	1	Software bug; Damage from reverse voltage spike on relay coil release; Hardware failure	1	Visual	1	1	None	None	L
1.6.2	Heated Bed	RPi	Controller failure/restart with GPIO low	Mains relay opens	All power to printer is cut	-	1	Software bug; Damage from reverse voltage spike on relay coil release; Hardware failure	2	Visual	1	2	None	None	L
Toolhead Assy															
2.1.1	Toolhead	Cartridge Heater	Short circuit	Lowered heating element resistance	Unexpected temperature rise for a given power input	Fire risk	10	Manufacturing defect; Component damage	2	Current fuse; Thermistor + SW control loop	4	80	Thermistor + SW control loop	Don't overspec heater wattage beyond what is needed for intended volumetric flow	L
2.1.2	Toolhead	Cartridge Heater	Open circuit	No power input to heater	System fails to reach desired temperature	-	1	Motion fatigue; Improper strain relief; Caught in motion system	4	Thermistor + SW control loop	3	12	Thermistor + SW control loop	Use motion rated wire	L
2.1.3	Toolhead	Cartridge Heater	Loose wire connection	Increased electrical resistance	Overheating at wire junction	-	6	Vibration; Exposure to high temperature on connector; Corrosion	4	Manual via thermal imager; Thermal fuse; Current fuse;	3	72	Use of vibration and high temp rated connectors	Ensure connector are temp and vibration rated	L
2.2.1	Toolhead	Thermistor	Short circuit PTC thermistor wire	Thermistor resistance decreases to zero	Controller interprets temperature lower than actual		3	Motion fatigue; Improper strain relief; Caught in motion system	1	SW control loop	2	6	SW control loop	None	L
2.2.2	Toolhead	Thermistor	Open circuit PTC thermistor wire	Thermistor resistance increases to infinity	Controller interprets temperature higher than actual		1	Motion fatigue; Improper strain relief; Caught in motion system	4	SW control loop	2	8	SW control loop	None	L
2.3.1	Toolhead	Contactor	Stuck closed	Contacts welded together	Controller unable to switch contactor off	Power continues to flow downstream	6	Damage from overcurrent; Frequent cycling with large loads applied; Controller lockup	1	Visual	7	42	Switch off mosfet before switching off contactor & vice versa to minimize spark	Switch off mosfet before switching off contactor & vice versa to minimize spark	L

2.4.1	Toolhead	MCU	Controller failure with outputs high	Contactor outputs stay closed; mosfets switch on with 100% duty cycle	Power continues to flow to heater	Fire risk	10	Software bug; Hardware failure / mosfet fused closed; Damage from reverse voltage spike on contactor release	2	Current fuse on cartridge heater; Thermistor on heater + SW control loop; Klipper/moonraker timeout on RPI	4	80	Moonraker control loop + mains relay	None	L
2.4.2	Toolhead	MCU	Controller failure with outputs low	Contactor outputs release; mosfet switches off	Heater does not receive power	-	1	Software bug; Hardware failure	1	Klipper/moonraker timeout on RPI	3	3	Moonraker control loop + mains relay	None	L
2.5.1	Toolhead	RPi	Controller failure/restart with GPIO high	Mains relay stays closed; printer continues to operate	MCU times out	-	1	Software bug; Damage from reverse voltage spike on contactor coil release; Hardware failure	1	Visual	1	1	None	None	L
2.5.2	Toolhead	RPi	Controller failure/restart with GPIO low	Mains relay opens	All power to printer is cut	-	1	Software bug; Damage from reverse voltage spike on contactor coil release; Hardware failure	2	Visual	1	2	None	None	L
Chamber Heater Assy															
3.1.1	Chamber Heater	PTC Heater	Short circuit	Lowered heating element resistance	Unexpected temperature rise for a given power input	Fire risk	10	Manufacturing defect; Component damage	1	Thermal fuse; Current fuse; Thermistor + SW control loop	2	20	Thermal fuse; Current fuse; Thermistor + SW control loop	None	L
3.1.2	Chamber Heater	PTC Heater	Open circuit mains wire	No power input to heater	System fails to reach desired temperature	-	2	Vibration; Improper strain relief; Caught in motion system	2	Thermistor + SW control loop	2	8	Thermistor + SW control loop	None	L
3.1.3	Chamber Heater	PTC Heater	Open circuit PTC thermistor wire	Thermistor resistance increases to infinity	Controller interprets temperature higher than actual	-	1	Vibration; Improper strain relief; Caught in motion system	4	SW control loop	2	8	SW control loop	None	L
3.1.4	Chamber Heater	PTC Heater	Short circuit PTC thermistor wire	Thermistor resistance decreases to zero	Controller interprets temperature lower than actual	-	3	Vibration; Improper strain relief; Caught in motion system	1	SW control loop	2	6	SW control loop	None	L
3.1.5	Chamber Heater	PTC Heater	Mains wire insulation breakdown	Exposed mains voltage	Electric shock risk	-	7	Mechanical damage	3	Visual	7	147	Grounded metal chassis	None	M
3.1.6	Chamber Heater	PTC Heater	Loose mains wire connection	Increased electrical resistance	Overheating at wire junction	-	6	Vibration; Exposure to high temperatures; Corrosion	2	Manual via thermal imager; Thermal fuse; Current fuse;	3	36	Use vibration and high temp rated connectors	Ensure connector are temp and vibration rated	L
3.1.7	Chamber Heater	PTC Heater	Melted plastic heater tabs	Heater sags down onto metal mounting plate	-	-	4	Exposure to high temperatures	2	Visual	5	40	None	Design mounting plate to retain heater even in the event of mount failure	L
3.2.1	Chamber Heater	Metal Mount	Broken AC ground connection	Exposed metal surface with floating electrical potential	Electric shock risk	-	7	Vibration; Improper strain relief; Caught in motion system	2	Visual	7	98	None	????	M
3.3.1	Chamber Heater	SSR	Stuck closed	Relay output can no longer be switched off	Power continues to flow to heater	Fire risk	10	Damage from overcurrent or large inrush; Hardware failure; Controller lockup	2	Thermal fuse on heater; Thermal fuse on SSR; Current fuse; Thermistor on heater + SW control loop	2	40	Thermal fuse on heater; Thermal fuse on SSR; Current fuse; Thermistor on heater + SW control loop	None	L
3.3.2	Chamber Heater	SSR	Stuck open	Relay output can no longer be switch on	Bed heater does not receive power	-	1	Hardware failure; Upstream component damage	1	Thermistor on heater + SW control loop	1	1	Themistor on heater + SW control loop	None	L
3.3.3	Chamber Heater	SSR	Overheating	Thermal de-rating	Temperature rise	Fire risk	10	Improperly specced heatsink; Overcurrent	3	Thermal fuse on SSR	2	60	Thermal fuse on SSR; adequate heatsink for load current and ambient temperature	None	L
3.4.1	Chamber Heater	Contactor	Stuck closed	Contacts welded together	Controller unable to switch contactor off	Power continues to flow downstream	6	Damage from overcurrent; Frequent cycling with large loads applied; Controller lockup	1	Visual	7	42	Switch off SSR before switching off contactor & vice versa to minimize spark	Switch off SSR before switching off contactor & vice versa to minimize spark	L
3.5.1	Chamber Heater	Fans	Stalled	Fan no longer spins when power is applied	Fan is unable to assist in regulating heater core temperature	Chamber temperature drops	5	Mechanical damage; Exposure to high temperatures; Blades jammed with loose debris	3	Rotor lock alarm signal; Thermistor on heater + SW control loop	2	30	High temp rated fans; Controller rotor monitoring	None	L
3.6.1	Chamber Heater	MCU	Controller failure with outputs high	Contactor outputs stay closed; SSRs switch on with 100% duty cycle	Power continues to flow to heater	Fire risk	10	Software bug; Hardware failure / mosfet fused closed; Damage from reverse voltage spike on contactor release	2	Thermal fuse on chamber heater; Thermal fuse on chamber SSR; Current fuse on chamber SSR; Thermistor on heater + SW control loop; Klipper/moonraker timeout on RPI	1	20	Moonraker control loop + mains relay	None	L
3.6.2	Chamber Heater	MCU	Controller failure with outputs low	Contactor outputs release; SSR switches off	Heater does not receive power	-	1	Software bug; Hardware failure	1	Klipper/moonraker timeout on RPI	3	3	Moonraker control loop + mains relay	None	L
3.7.1	Chamber Heater	RPi	Controller failure/restart with GPIO high	Mains relay stays closed; printer continues to operate	MCU times out	-	1	Software bug; Damage from reverse voltage spike on relay coil release; Hardware failure	1	Visual	1	1	None	None	L
3.7.2	Chamber Heater	RPi	Controller failure/restart with GPIO low	Mains relay opens	All power to printer is cut	-	1	Software bug; Damage from reverse voltage spike on relay coil release; Hardware failure	2	Visual	1	2	None	None	L