

Design Failure Mode and Effects Analysis Worksheet

Item and Function/Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Potential Sub-effect(s) of Failure	Severity Potential Cause(s)/Mechanisms of Failure	Occurrence Current Controls - Prevention	Current Controls - Detection	Detection RPN	Recommended Action*	
Gravity Pump	Leakage of media at tubing interface	Reduced experiment run time	Embryo not exposed to growth factor for sufficient time to alter development	5 Material choice/interface technique	1 Material choice	Visual monitoring	3 15	None	
		Increased cost to run experiment	Decreased number of test runs	4 Material choice/interface technique	1 Material choice	Visual monitoring	3 12	None	
		Increased man-hours required to monitor experiment	Decreased number of test runs	4 Material choice/interface technique	1 Material choice	Visual monitoring	3 12	None	
		Change in media flow rate	Embryo dislodged	7 Material choice/interface technique	1 Material choice	Visual monitoring	5 35		
			Not enough nutrient/growth factor delivery	5 Material choice/interface technique	1 Material choice	Sampling of reservoir concentrations	6 30	None	
			Embryo death	8 Material choice/interface technique	1 Material choice	Visual monitoring	4 32	Design better sealing mechanism	
		Absorption of solutes into container wall	Change in fishwater solute concentration	Unwanted embryo development changes	6 Material choice/reduction of nutrients and growth factors	2 Material choice	Visual inspection of embryo post experiment	9 108	Change gravity pump material
			Embryo death	8 Material choice	2 Material choice	Visual monitoring	6 96	None	
			Change in growth factor concentration	Unwanted embryo development changes	4 Material choice/reduction of nutrients and growth factors	2 Material choice	Visual inspection of embryo post experiment	9 72	None
			Embryo death	8 Material choice	2 Material choice	Visual monitoring	6 96	None	
		Degradation of epoxy/tubing interface	Addition of new compounds to fishwater	Unwanted embryo development changes	6 Material choice/too many solutes in fishwater	3 Material choice	Visual inspection of embryo post experiment	6 108	None
			Embryo death	8 Material choice	6 Material choice	Visual monitoring	4 192	None	
			Change in media flow rate	Embryo dislodged	7 Material choice	5 Material choice	Visual monitoring	4 140	None
				Not enough nutrient/growth factor delivery	5 Degradation product blocks/denatures growth factor	3 Material choice	Sampling of reservoir concentrations	7 105	None
				Embryo death	8 Degradation product blocks/denatures solutes	3 Material choice	Visual monitoring	4 96	None
		Degradation of container	Addition of new compounds to fishwater	Unwanted embryo development changes	6 Material choice	2 Material choice	Visual inspection of embryo post experiment	5 60	None
				Embryo death	8 Material choice	1 Material choice	Visual monitoring	4 32	None
			Change in media flow rate	Embryo dislodged	6 Degradation products blocks channel/tubing	1 Material choice	Visual monitoring	3 18	None

SUPPLEMENTAL FIG. S1. The final design failure mode and effects analysis worksheet for the micro fluidic zebrafish bioreactor project. This analyzes the issues the students addressed in the course of designing, microfabricating, and testing the bioreactor with and without zebrafish embryos. The levels of severity are relative and assigned after discussion among the students on the team.

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			Not enough nutrient/growth factor delivery	5 Degradation products blocks channel/tubing	1 Material choice	Sampling of reservoir concentrations	5 25	None
	Media flows too rapidly	Loss of growth factor	More money to run experiment	6 Channel too large	3 Channel mold	Visual monitoring	5 90	Reduce size of channel mold
			Embryo death	8 Degradation products blocks channel/tubing	3 Material choice	Visual monitoring	4 96	None
Tubing to Chip	Leakage of media at tubing/chip interface	Growth factor enters Petri dish	Unwanted embryo development changes	6 Material choice/interface technique	2 Material choice	Visual inspection of embryo post experiment	7 84	None
			Embryo death	8 Fishwater not delivered to lower channel	2 Material choice	Visual monitoring	2 32	None
		Overflow of Petri dish	Damage to device	8 Petri dish too small	1 Large Petri dish during testing	Visual monitoring	2 16	None
			Loss of growth factor	7 Petri dish too small	2 Large Petri dish during testing	Visual monitoring	4 56	None
		Reduced flow through channel	Not enough growth factor delivered to embryo during course of experiment	6 Material choice/interface technique	3 Material choice	Visual monitoring	5 90	None
			Too much growth factor diffuses to embryo	6 Material choice/interface technique	2 Material choice	Sampling of reservoir concentrations	5 60	None
	Absorption of solutes into tubing wall	Change in fishwater solute concentration	Unwanted embryo development changes	6 Material choice/reduction of nutrients and growth factors	2 Material choice	Visual inspection of embryo post experiment	8 96	None
			Embryo death	8 Material choice/reduction of nutrients and growth factors	2 Material choice	Visual monitoring	4 64	None
		Change in growth factor concentration	Unwanted embryo development changes	6 Material choice/reduction of nutrients and growth factors	3 Material choice	Visual inspection of embryo post experiment	8 144	None
			Embryo death	8 Material choice/reduction of nutrients and growth factors	3 Material choice	Visual monitoring	4 96	None
	Degradation of epoxy/tubing interface	Addition of new compounds to fishwater	Unwanted embryo development changes	6 Degradation product blocks/denatures growth factor	2 Material choice	Visual inspection of embryo post experiment	8 96	None
			Embryo death	8 Degradation product blocks/denatures growth factor	2 Material choice	Visual monitoring	4 64	None
		Change in media flow rate	Embryo dislodged	5 Degradation product blocks channel	2 Material choice	Visual monitoring	3 30	None

SUPPLEMENTAL FIG. S1. (Continued)

Design Failure Mode and Effects Analysis Worksheet

Item and Function/Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Potential Sub-effect(s) of Failure	Safety Potential Cause(s)/Mechanisms of Failure	Occurrence Current Controls - Prevention	Current Controls - Detection	Detection RPN	Recommended Action*
			Not enough nutrient/growth factor delivery	5 Degradation product blocks channel	2 Material choice	Sampling of reservoir concentrations	6 60	None
			Embryo death	8 Degradation product blocks channel	2 Material choice	Visual monitoring	4 64	None
	Degradation of tubing	Addition of new compounds to fishwater	Unwanted embryo development changes	6 Degradation product blocks channel	2 Material choice	Visual inspection of embryo post experiment	8 96	None
			Embryo death	8 Degradation product blocks channel	2 Material choice	Visual monitoring	4 64	None
		Change in media flow rate	Embryo dislodged	4 Degradation product blocks channel	3 Material choice	Visual monitoring	3 36	None
			Not enough nutrient/growth factor delivery	5 Degradation product blocks channel	3 Material choice	Sampling of reservoir concentrations	5 75	None
			Embryo death	8 Degradation product blocks channel	3 Material choice	Visual monitoring	4 96	None
Microfluidic Chip	Degradation of channel by fishwater flow	Altered flow profile	Embryo dislodged	7 Flow rate increases pushing embryo out of funnel	2 Material choice/flow control	Visual monitoring	5 70	Replace old chip with new chip
			Shear lyses embryo	8 Flow rate increases	2 Material choice/flow control	Visual monitoring	6 96	Replace old chip with new chip
			Growth factor not delivered to embryo	7 Diffusivity too low at high flow rate	3 Material choice/flow control	Visual inspection of embryo post experiment	7 147	Replace old chip with new chip
		Leakage of growth factor into surrounding fishwater	Unwanted embryo development changes	6 Embryo cannot fully plug funnel	3 Material choice/flow control	Visual inspection of embryo post experiment	7 126	Replace old chip with new chip
			Not enough growth factor delivered to embryo	5 Growth factor diffuses into surrounding fishwater	3 Material choice/flow control	Sampling of fishwater concentrations	8 120	Replace old chip with new chip
		PDMS enters flow	Embryo dislodged	6 Degradation product pushes embryo out of funnel	2 Material choice/flow control	Visual monitoring	6 72	Replace old chip with new chip
			Unwanted embryo development changes	5 Degradation product interacts with embryo	2 Material choice/flow control	Visual inspection of embryo post experiment	8 80	Replace old chip with new chip
			Embryo death	8 Degradation product blocks channel	2 Material choice/flow control	Visual monitoring	5 80	Replace old chip with new chip
	Degradation of funnel by fishwater flow	Leakage of growth factor into surrounding fishwater	Unwanted embryo development changes	5 Degradation product interacts with embryo	2 Material choice/flow control	Visual inspection of embryo post experiment	8 80	Fabricate with smoother mold
		Expansion of funnel	Embryo dislodged	8 Degradation reduces surface tension, releasing embryo	2 Material choice/flow control	Visual monitoring	3 48	Fabricate with smoother mold

SUPPLEMENTAL FIG. S1. (Continued)

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Item and Function/Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Potential Sub-effect(s) of Failure	Severity Potential Cause(s) of Failure	Occurrence Current Controls - Prevention	Current Controls - Detection	Detection RPN	Recommended Action*
			Growth factor dispersed around embryo	7 Growth factor diffuses into surrounding fishwater	2 Material choice/flow control	Visual inspection of embryo post experiment	5 70	Fabricate with smoother mold
		PDMS enters flow	Embryo dislodged	6 Degradation product pushes embryo out of funnel	2 Material choice/flow control	Visual monitoring	4 48	None
			Unwanted embryo development changes	6 Degradation product interacts with embryo	2 Material choice/flow control	Visual inspection of embryo post experiment	8 96	Replace old chip with new chip
			Embryo death	8 Degradation product interacts with embryo	2 Material choice/flow control	Visual monitoring	5 80	Replace old chip with new chip
	Embryo lodged too low into funnel	Too much pressure exerted on embryo	Embryo lysed	8 Funnel exerts too much physical pressure	4 Insertion guide	Visual monitoring	4 128	None - Remove embryo and replace
			Abnormal development occurs	5 Physical deformation causes development change	3 Insertion guide	Visual inspection of embryo post experiment	9 135	None - Remove embryo and replace
			Embryo enters channel	5 Pressure pushes embryo through funnel	3 Insertion guide	Visual monitoring	2 30	None - Remove embryo and replace
			Embryo lyses during removal	9 Embryo lodged too low in funnel	2 Insertion guide	Visual monitoring	6 108	Alter removal method
	Funnel too large	Embryo enters channel	Embryo lost	9 Funnel too large	2 Funnel Mold	Visual monitoring	5 90	Reduce size of funnel mold
	Embryo lodged too high in funnel	Embryo does not enter far enough into funnel	Not enough growth factor delivered to embryo	6 Growth factor does not diffuse to embryo	6 Insertion guide	Visual monitoring	6 216	None - Remove embryo and replace
			Embryo dislodged	5 Not enough pressure exerted on embryo	5 Insertion guide	Visual monitoring	2 50	None - Remove embryo and replace
			Embryo lysed	8 Too much shear on embryo	2 Insertion guide	Visual monitoring	2 32	None - Remove embryo and replace
	Degradation of PDMS	Contamination of fishwater	Unwanted embryo development changes	6 Degradation product interacts with embryo	3 Material choice	Visual inspection of embryo post experiment	8 144	Replace old chip with new chip
			Embryo death	8 Degradation product interacts with embryo	3 Material choice	Visual monitoring	5 120	Replace old chip with new chip
	Bubble forms in channel	Bubble lodges in funnel	Embryo cannot lodge in funnel	7 Inadequate flushing/Embryo cannot displace bubble	5 Flushing technique	Visual monitoring	3 105	Increase system flush time
			Fishwater cannot surround embryo	8 Inadequate flushing/Bubble removes aqueous environment	5 Flushing technique	Visual monitoring	4 160	Increase system flush time
			Embryo death	8 Inadequate flushing/Bubble removes aqueous environment	5 Flushing technique	Visual monitoring	4 160	Increase system flush time

SUPPLEMENTAL FIG. S1. (Continued)

Design Failure Mode and Effects Analysis Worksheet

Item and Function/Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Potential Sub-effect(s) of Failure	Severity Potential Cause(s)/Mechanisms of Failure	Occurrence Current Controls - Prevention	Current Controls - Detection	Detection ICM	Recommended Action*
			Growth factors not delivered	9 Inadequate flushing/Bubble removes aqueous environment	3 Flushing technique	Visual monitoring	7 189	Increase system flush time
		Flow disrupted	Embryo dislodged	6 Inadequate flushing/Bubble removes aqueous environment	5 Flushing technique	Visual monitoring	5 150	Increase system flush time
	Evaporation through chip	Fishwater/growth factor concentrations change	Too much growth factor delivered	8 Reduced water concentration raises growth factor concentration	1 Chip submerged in fishwater	Sampling of reservoir concentrations	8 64	Increase channel size
			pH balance shift causes embryo development change	4 Chip not stored in proper environment	4 Chip submerged in fishwater	Sampling of reservoir concentrations	4 64	None
			Embryo death	8 Chip not stored in proper environment	4 Chip submerged in fishwater	Visual monitoring	5 160	Increase channel size
	Chip dries out	Dimensions changed	Embryo cannot lodge in funnel	7 Chip not stored in proper environment	1 Chip submerged in fishwater/stored in sealed container	Visual monitoring	2 14	Design improve storage technique
			Embryo falls into channel	7 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Visual monitoring	3 42	Design improve storage technique
			Flow rate dislodges embryo	7 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Visual monitoring	4 56	Design improve storage technique
			Not enough growth factor delivered to embryo	8 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Sampling of reservoir concentrations	8 128	Design improve storage technique
			Too much growth factor delivered	8 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Sampling of reservoir concentrations	8 128	Design improve storage technique
			Embryo death	8 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Visual monitoring	5 80	Design improve storage technique
			Gravity pump disconnects	3 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Visual monitoring	1 6	None
			Reservoir disconnects	2 Chip not stored in proper environment	2 Chip submerged in fishwater/stored in sealed container	Visual monitoring	1 4	None
Tubing to Reservoir	Leakage of media at tubing/chip interface	Growth factor enters Petri dish	Unwanted embryo development changes	4 Material choice/interface technique	2 Material choice	Visual inspection of embryo post experiment	7 56	None
			Embryo death	8 Material choice/interface technique	3 Material choice	Visual monitoring	4 96	None

SUPPLEMENTAL FIG. S1. (Continued)

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Item and Function/Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Potential Sub-effect(s) of Failure	Severity Potential Cause(s)/Mechanisms of Failure	Occurrence Current Controls - Prevention	Current Controls - Detection	Detection RPN	Recommended Action*
		Overflow of Petri dish	Damage to device	8 Material choice/interface technique	2 Material choice	Visual monitoring	3 48	None
			Loss of growth factor	8 Material choice/interface technique	4 Material choice	Visual monitoring	6 192	Increase size of Petri dish
		Reduced flow through channel	Not enough growth factor delivered to embryo during course of experiment	6 Material choice/interface technique	2 Material choice	Sampling of reservoir concentrations	4 48	None
			Too much growth factor diffuses to embryo	7 Material choice/interface technique	3 Material choice	Sampling of reservoir concentrations	6 126	Design improved interface
	Degradation of epoxy/tubing interface	Addition of new compounds to fishwater	Unwanted embryo development changes	5 Degradation product alters embryo development	3 Material choice	Visual inspection of embryo post experiment	8 120	Use different epoxy
			Embryo death	8 Degradation product alters embryo development	3 Material choice	Visual monitoring	5 120	Use different epoxy
		Change in media flow rate	Embryo dislodged	4 Degradation product blocks tubing	3 Material choice	Visual monitoring	4 48	None
			Not enough nutrient/growth factor delivery	6 Degradation product blocks tubing	3 Material choice	Sampling of reservoir concentrations	7 126	Use different epoxy
			Embryo death	8 Degradation product blocks tubing	3 Material choice	Visual monitoring	5 120	Use different epoxy
Collection Reservoir	Leakage of media at tubing interface	Damage to surrounding equipment	Increased cost of operation	4 Material choice/interface operation	2 Material choice	Visual monitoring	2 16	None
	Absorption of solutes into container wall	Change in concentration of collection fluid	Unable to accurately analyze output	4 Material choice	2 Material choice	Sampling of reservoir concentrations	6 48	None
			Reduced noggin recycling	5 Material choice	2 Material choice	Sampling of reservoir concentrations	5 50	None
	Degradation of epoxy/tubing interface	Damage to surrounding equipment	Increased cost of operation	4 Material choice	2 Material choice	Visual monitoring	2 16	None
		Change in concentration of collection fluid	Unable to accurately analyze output	4 Material choice	2 Material choice	Sampling of reservoir concentrations	4 32	None
			Reduced noggin recycling	4 Material choice	2 Material choice	Sampling of reservoir concentrations	4 32	None

* No action is recommended for RPN values less than 100
 ** Responsibility and Action Taken to be determined once device testing begins

SUPPLEMENTAL FIG. S1. (Continued)