NE529
RISK ASSESSMENT
Failure Modes & Effects Analysis
4

R. A. Borrelli

University of Idaho

Idaho Falls Center for Higher Education

University of Idaho
Department of Nuclear Engineering
and Industrial Management

Learning objectives

Chapter 11 in book

Explain and analyze failures for process, system, product in detail

My m/o is to use this time to show the concepts with my examples

See case studies and literature in the OER to supplement the lecture

Choose what is most interesting and relevant to you

Immersive critical thinking – always the three questions

Learning nodes

What FMEA is

FMEA definitions

Utility of FMEA

FMEA procedure

Construct flow chart

Define failure modes

Establish failure effects

Failure mode matrix examples

Evaluate severity

Estimate failure frequency

Calculate Risk Priority Number (RPN)

Root cause analysis

Mitigation

It’s really hard to quantify risk

PRA wasn’t ‘invented’ until there were 2-ish decades of operational data

Getting any data cohorts for an FMEA is ideal but probably difficult

Can use related historical or similarly accident data

Draw upon expert judgement and best estimates

Can use a Delphi technique

Iterative way to develop consensus about something

What FMEA is

FMEA helps to develop a firm understanding of what a failure is prior to risk analysis

Detailed document that identifies ways in which process/product fails

Or does not meet critical requirements

Inductive – Sherlock Holmes

Bottom up, forward search approach

Living document that lists all the possible causes of failure

Items can be generated to determine types of controls/changes in procedures

Systematic way to identify and prevent problems in processes and products before they occur

Design driven approach

FMEA is a proactive tool to assist in new service design or enhancement of existing processes

What was the purpose of the PHA?

How will this relate?

FMEA might be more conducive when dealing with monetary loss

Most common for assessment technique at initial stages of system development

Maximize design life

FMEA definitions

Let’s start with some definitions

Failure mode

Ways in which a process can fail

Interrupts continuity of production

Loss of assets (not just money)

Unavailability of equipment

Deviation from normal operation

Not meeting target expectations

Secondary defects

Potential (failure) effect (consequence)

Result of failure mode

Some more likely to occur than others

Include regulatory requirements

Let’s continue with some definitions

Risk of failure

Each potential effect carries risk associated with it

Consequences

Frequency

Risk Priority Number

Nominal value assigned to risk for each failure

Can results from a PHA be applied?

Why is FMEA effective?

Identifies areas of failure in process, system, component, or procedure

Effects of the process, system, component, or procedure failing

Failure causes (common cause)

Reducing the probability of failure

Improving the means of detecting the causes of failure

Risk ranking of failures, allowing risk informed decisions by those responsible

A starting point from which the control plan can be created

Decomposition of risk – focus on the areas where risk can be reduced

FMEA procedure

Flowchart

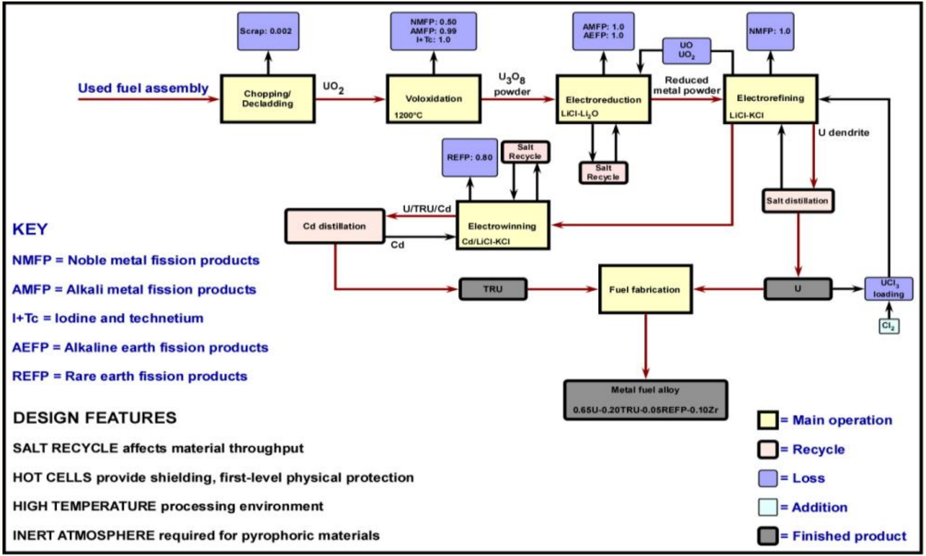
Construct a detailed flow chart of the process

Multi-disciplinary participation of all those involved in the process

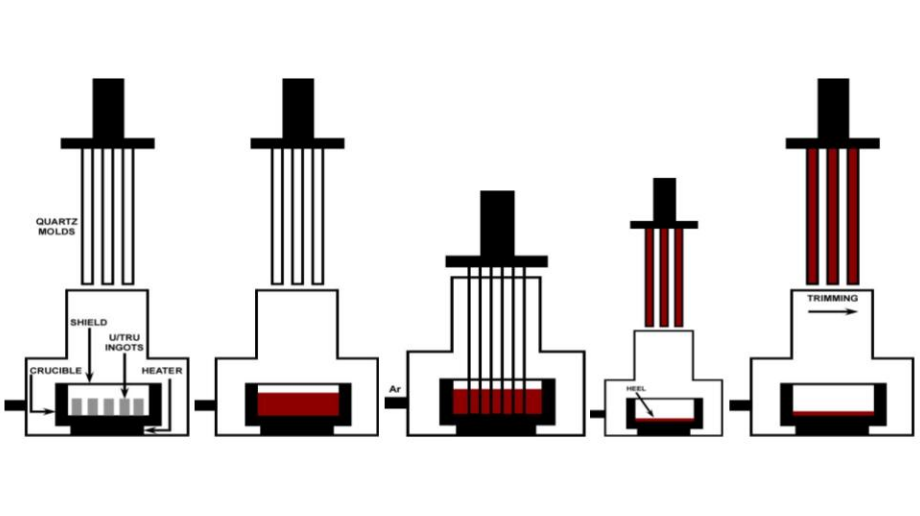
Allocate plenty of time for this step

Be as complete as possible

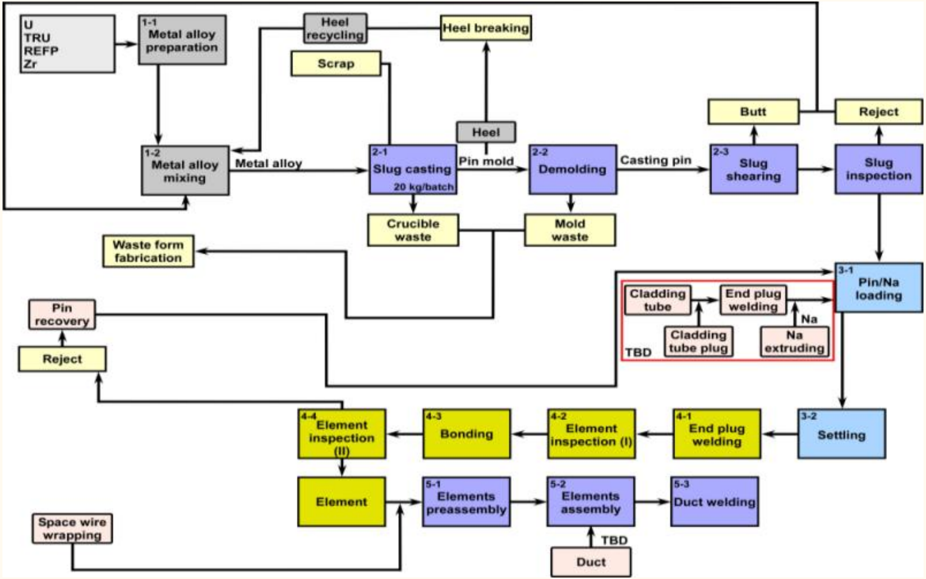
Flow charting software can help (or write your own)



Used fuel assembly
Chopping/ Decladding
Scrap: 0.002
UO2
Voloxidation
1200°C
NMFP: 0.50
AMFP: 0.99
I+Tc: 1.0
U3O8 powder
Electroreduction
LiCl-Li2O
AMFP: 1.0
AEFP: 1.0
UO
UO2
Salt Recycle
Reduced metal powder
Electrorefining
LiCl-KCl
NMFP: 1.0
U dendrite
Salt distillation
REFP: 0.80
Salt Recycle
U/TRU/Cd
Electrowinning
Cd/LiCl-KCl
Cd distillation
Cd
TRU
Fuel fabrication
U
UCl3 loading
Cl2
Metal fuel alloy
0.65U-0.20TRU-0.05REFP-0.10Zr
KEY
NMFP = Noble metal fission products
AMFP = Alkali metal fission products
I+Tc = Iodine and technetium
AEFP = Alkaline earth fission products
REFP = Rare earth fission products
DESIGN FEATURES
SALT RECYCLE affects material throughput
HOT CELLS provide shielding, first-level physical protection
HIGH TEMPERATURE processing environment
INERT ATMOSPHERE required for pyrophoric materials
= Main operation
= Recycle
= Loss
= Addition
= Finished product


QUARTZ
MOLDS
SHIELD
U/TRU
INGOTS
CRUCIBLE
HEATER
Ar
HEEL
TRIMMING

Process steps



Define failure modes

Determine how each step could possibly fail

Getting material into the crucible – effect – cause

Heater fails to sufficiently melt all the metal – effect – cause

Vacuum cannot be induced – effect – cause

Molds get stuck or break – effect – cause

Cannot remove heel – effect – cause

Failure mode matrix examples

DATE:	1/4/93	PAGE:	1 of 1
PLANT:		SYSTEM:	Cooling Water Chlorination System
ITEM:	Pressure Check Valve	REFERENCE:	

FAILURE MODE	CAUSE(S)	OPERATIONAL MODE	FAILURE EFFECTS	FAILURE DETECTION METHOD	COMPENSATING PROVISIONS	SEVERITY CLASS	REMARKS/ ACTIONS
Too much flow through valve	Both internal pressure valves fail open	Operation	Excessive chlorine flow to Tower Water Basin - high chlorine level in cooling water - potential for excessive corrosion in cooling water system	Rotameter Daily testing of cooling water chemistry	Relief valve on Pressure check valve outlet	III	None
Too little flow through valve	One or both internal pressure valves fail closed	Operation	No/low chlorine flow to Tower Water Basin - low chlorine level in cooling water - potential for excessive biological growth in cooling water system - reduction in heat transfer	Rotameter Daily testing of cooling water chemistry	Automatic temperature controllers at most heat exchangers	IV	None
Chlorine flow to environment	Internal relief valve sticks open Both internal pressure valves fail open and relief valve opens	Operation	Potential low chlorine flow to Tower Water Basin - see above Chlorine released to environment - potential personnel injury due to exposure	Distinctive odor	Pressure check valve located outdoors - unlikely to accumulate significant concentration	III	Action Item: Consider venting relief valve above ground level

Figure 2: Potential Failure Modes and Effects Analysis (FMEA) on the Service Provided at the Special Olympics—an Assessment of Hotel Service

Process responsibility: FMEA date: (Rev):

Process function requirement	Potential failure mode	Potential effect(s) of failure	Severity	Class	Potential cause(s)/ mechanism(s) of failure	Occur	Current process control	Detect	RPN	Recommended action(s)	Responsibility and target complete date	Action results: Actions taken	Action results: Severity	Action results: Occurrence	Action results: Detection	Action results: RPN
Service desk	Cannot register in time	Complaints	5		Lack of language and communication skills, support of volunteers not sufficient	4	No plan on training content; training and volunteer support not sufficient	3	72	Make complete training plan, implement personnel training and provide enough volunteers						
Guest support	Lack of barrier-free facility	Inconvenience and injury	10		Cannot provide barrier-free facility	3	Providing barrier-free facility	7	210	Add barrier-free facility						
	Unclear signs	Can't find the room			Signs out of date and overdue; identification not removed	4	Post new signs			Periodic inspection and maintenance						
	Pooly planned equipment	Personal injury			Inappropriate equipment	3	Move, replace and/or improve equipment			Periodic inspection and repair						
Food service	Substandard food items	Disease or injury	5		No supplier control system, procedure or method of purchasing and/or inspection	3	Random purchasing and random inspection	3	72	Establish inspection procedure and method; strengthen outgoing product control						
					Food-preserving equipment and environment inconsistent with requirement	4	No requirements on storage equipment, maintenance or periodic cleaning of warehouse	7	210	Set requirements on storage equipment and environment; provide periodic maintenance						
	Food goes bad	Disease or injury	10		Raw material past shelf life	6	No control on the raw material	8	240	Periodic inspection						
					Packing damage		No control of packaging	3	120	Regular loading/unloading						
Medical service	Service not in time	Illness changes for the worse	10		No 24-hour service		12-hour service	3	180	Provide 24-hour service						

Establish failure effects

Determine the effects (consequences) of each possible failure

Getting material into the crucible – crucible breaks

Heater fails to sufficiently melt all the metal – molds might crack; not sufficiently take up all the metal

Vacuum cannot be induced – no injection

Molds get stuck or break – big mess; liquid metal spills onto equipment

Cannot remove heel – replace crucible; store heel

Evaluate severity

Apply (or find) a Severity Rating Scale

10 – Dangerously high – Injury

9 – Extremely high – Regulatory noncompliance

8 – Very high – Equipment inoperable or unfit for use

7 – High – High degree of customer dissatisfaction/bad results

6 – Moderate – Partial malfunction

5 – Low – Some performance loss

4 – Very low – Minor performance loss

3 – Minor – Identifiable product flaws

2 – Very minor – Not readily apparent product flaws

1 – None

Severity for fuel fabrication failure modes

Getting material into the crucible – crucible breaks

6 – Moderate

Failure results in subsystem or partial malfunction of the product

Heater fails to sufficiently melt all the metal – molds might crack; not take up all the metal

6 – Moderate

Failure results in subsystem or partial malfunction of the product

Vacuum cannot be induced – no injection

6 – Moderate

Failure results in subsystem or partial malfunction of the product

Severity for fuel fabrication failure modes

Molds get stuck or break – big mess; liquid metal spills onto equipment

8 – Very high

Failure renders the unit inoperable or unfit for use

Cannot remove heel – replace crucible; store heel

6 – Moderate

Failure results in subsystem or partial malfunction of the product

Any shutdown interrupts material flow

Estimate failure frequency

Estimate failure frequency with an Occurrence Rating Scale

10 – Very high – 1 per day or more than 3 per 10 events

9 – Mid – 1 per 3,4 days or 3 per 10 events

8 – High – 1 per week or 5 per 100 events

7 – Mid – 1 per month or 1 per 100 events

6 – Moderate – 1 per 3 months or 3 per 1000 events

5 – Mid – 1 per 6 months or 1 per 10000 events

4 – Mid low – 1 per year or 6 per 100000

3 – Low – 1 per 1-3 years or 6 per 1 billion events

2 – Mid – 1 per 3-5 years or 2 per 1 billion events

1 – Remote – 1 per $>$5 years or less than 2 per 1 billion events

Occurrence for fuel fabrication failure modes

Getting material into the crucible – crucible breaks

6 – Moderate

1 occurrence every 3 months or 3 occurrences in 1000 events

Heater fails to sufficiently melt all the metal – molds might crack; not take up all the metal

7 – Moderate/High

1 occurrence every month or 1 occurrence in 100 events

Vacuum cannot be induced – no injection

6 – Moderate

1 occurrence every 3 months or 3 occurrences in 1000 events

Occurrence for fuel fabrication failure modes

Molds get stuck or break – big mess; liquid metal spills onto equipment

5 – Low/Moderate

1 occurrence every 6 months to 1 year or 1 occurrence in 10000 events

Cannot remove heel – replace crucible; store heel

7 – Moderate/High

1 occurrence every month or 1 occurrence in 100 events

Calculate Risk Priority Number (RPN)

Calculate, prioritize **RPN** for each failure mode

RPN = Severity $\times$ Occurrence

More quantitative than prior work we've done

RPN for fuel fabrication failure modes

Getting material into the crucible – crucible breaks

$6 \times 6 = 36$

Heater fails to sufficiently melt all the metal – molds might crack; not take up all the metal

$6 \times 7 = 42$

Vacuum cannot be induced – no injection

$6 \times 6 = 36$

Molds get stuck or break – big mess; liquid metal spills onto equipment

$8 \times 5 = 40$

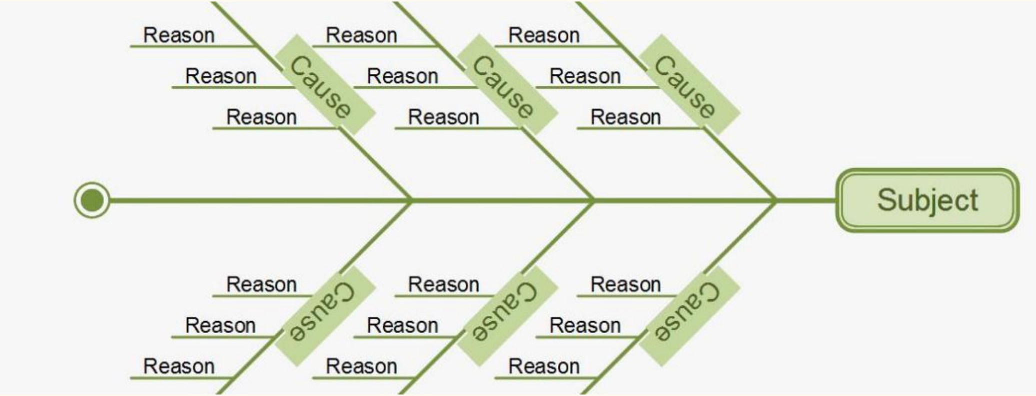
Cannot remove heel – replace crucible; store heel

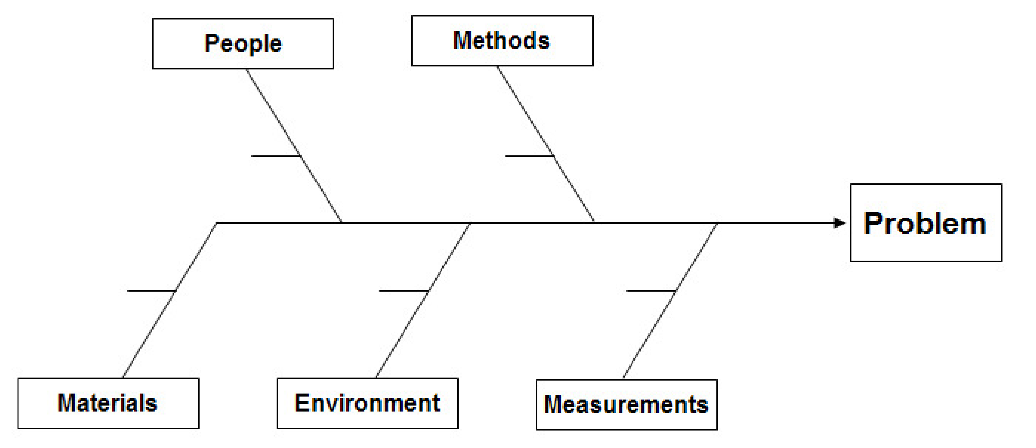
$6 \times 7 = 42$

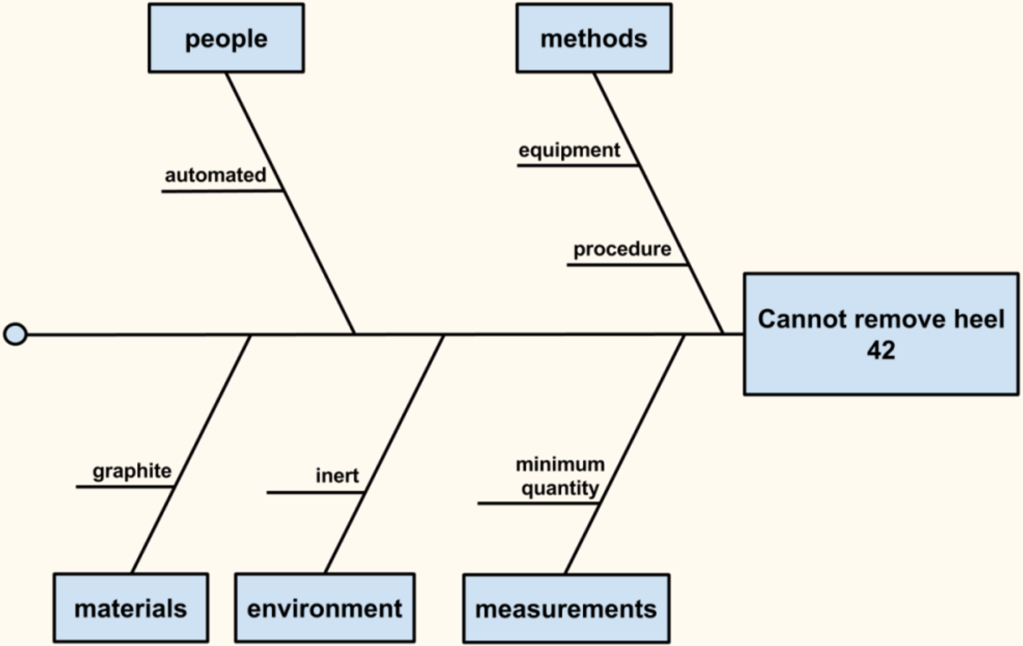
We can see that this is a way to initially quantify risk based on unknown frequencies

Root cause analysis

Conduct a root cause analysis for highest risk




People
Methods
Problem
Materials
Environment
Measurements


people
methods
automated
equipment
procedure
Cannot remove heel
42
graphite
inert
minimum
quantity
materials
environment
measurements

Causes to make the metal stick to the crucible and cannot remove it cleanly

Graphite is the wrong material

Inert atmosphere

Can induce vacuum

Maybe there has to be X grams of it before removing

We also have to be able to detect the material in the crucible

If the process is automated, it may be too complicated

Human hands might be needed

The removal process might need redesigning or optimization

Maybe heat the crucible and pour metal into separate container

Should be conducted by a team and be more in depth

Mitigation

Take action to eliminate or reduce the RPN

Decrease likelihood of occurrence

Decrease the severity of effects

Lab-scale testing of different crucible materials may show a preferable material

May also show that removal cannot be achieved unless there is 100 grams, etc.

Probably have a lot of crucibles on hand and maybe develop a clean, swap out procedure

May also show that removal cannot be achieved unless there is 100 grams, etc.

My expert opinion would be that the crucible is the primary root cause

Apply a 'Plan-Do-Study-Act' approach

What are we trying to accomplish?

Remove the heel without having it stick on the crucible

We have to measure the special nuclear material

Then maybe store it and recycle it back into the melter

How will we know that a change is an improvement?

Heel is removed cleanly

Probably need to conduct lab scale experiments

What changes can we make that will result in an improvement?

See fishbone discussion

Change material, procedures, environment

Iterative process – but only so many meetings and brainstorming; at some point you have to get the job done