

Delivering Manufacturable Solutions in Systems Engineering Projects

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I. Abstract

This report documents the contribution of the manufacturing engineer within a multi-disciplinary team tasked with developing a man-portable explosive device to neutralise an urban communications centre, in accordance with MOD requirements. It outlines the technical tools used, including QFD, PFMEA, and process control planning, to ensure that the proposed solution was not only functional but also manufacturable, safe, and compliant with relevant legislation.

The manufacturing engineer worked closely with the design, safety, and disposal engineers to align the concept with realistic process capabilities. PE-8 extrusion was selected as the optimal manufacturing route following analysis of risks, repeatability, and regulatory constraints. Communication was maintained through structured reviews, shared platforms, and defined technical hand-offs to ensure consistency across the lifecycle.

The report includes a full reflection on the presentation delivery, feedback response, and after-action review. It highlights key lessons, such as the need for early manufacturing involvement, traceable design-to-process alignment, and structured stakeholder interaction to achieve an integrated system outcome.

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1. Introduction

This report outlines the activities and contributions of the manufacturing engineer in a team-based concept development project. The objective was to develop a modular explosive device capable of neutralising a communications centre in an urban environment from a standoff distance of at least 100m. The system was required to be man-portable, meet Ministry of Defence (MOD) safety standards, and minimise collateral effects.

The project followed a structured systems engineering process, using design book methodology to ensure traceability from stakeholder requirements through to concept selection and manufacturing feasibility. Each team member represented a key discipline across the lifecycle, including design, manufacturing, safety, and disposal. This report focuses on the manufacturing input throughout that lifecycle.

The manufacturing engineer's role was to ensure the selected design could be produced safely, repeatably, and in compliance with relevant regulations. This included defining manufacturing requirements, assessing process risks, and ensuring that outputs from the design team were aligned with feasible and controlled production methods.

Sections of this report will cover the literature and tools underpinning manufacturing involvement in systems engineering; the role, communication, and

contribution of the manufacturing engineer; the outputs delivered to the wider team and a reflection on the process and lessons learned.

2. Literature Review

Manufacturing in systems engineering focuses on converting design outputs into repeatable, safe, and compliant processes. Design for Manufacture (DfM) ensures that constraints such as tooling, tolerances, safety, and cost are considered during design [1]. A design is not valid unless it can be built safely, within cost, and to required performance.

The design book process provides traceability through all stages of development, from initial requirements to process planning. It uses structured tools to weight and prioritise stakeholder requirements, ensuring consistent decision-making. This avoids subjective or isolated design actions and supports output alignment with project goals [2].

Requirement weighting starts with a pairwise comparison, ranking needs by importance. These feed into QFD1 [3], which assesses how each system function supports the prioritised requirements. In manufacturing, this highlights the processes most critical to delivering performance, safety, and repeatability. For this project, it drove early focus on the PE-8 filling process and its associated risks.

Process Failure Mode and Effects Analysis (PFMEA) complements Quality Function Deployment (QFD) by identifying where failure could occur during manufacturing. It guides risk mitigation based on the severity, occurrence, and detectability of each failure mode, particularly in processes involving explosives. Function Failure Mode and Effects Analysis (FFMEA) and Design FMEA (DFMEA) further support this approach by enabling human factors to be captured across system-level functions and hardware interactions. These tools ensure that risks from operator actions, such as incorrect setup, misalignment, or skipped checks, are addressed during both design and manufacturing planning [4].

Manufacturing is not an isolated phase but a systems-level input. Design outputs must account for manufacturing constraints early to ensure final assemblies are not only functional but buildable within real-world constraints. Human error is a known risk in energetic material handling, and processes must be designed with simplicity, clarity, and repeatability to minimise that risk [5]. Process FMEA (PFMEA) may also be used to analyse tasks directly involving operator decision-making, identifying where behaviour variability could lead to process failure.

Standards such as the Manufacture and Storage of Explosives Regulations 2005 (MSER) [6] define legal safety controls. ISO 9001 and ISO 14001 [7] support quality and environmental assurance. Together, these frameworks ensure that chosen manufacturing methods, such as PE-8 extrusion into drop-in pellets, meet regulatory, quality, and functional expectations.

3. Understanding of Role and Communication with Team

3.1. Role of the Manufacturing Engineer

The manufacturing engineer assessed feasibility, repeatability, and compliance throughout the project. Early involvement in the Gemba visit [8] (Appendix 1) provided understanding of operator needs and handling constraints.

Manufacturing input became more significant during concept selection, where discussions with the design engineer focused on whether proposed fill methods were practical. Melt-cast fills were ruled out due to the small pellet size required, which is not suited to cast filling. PE-8 extrusion was selected as a more controlled and practical method.

The manufacturing engineer also supported the safety and disposal engineers. Waste disposal was simplified by the manufacturer's in-house burning capability. The safety engineer approved this and focused on in-service risks.

Process risk was assessed using PFMEA, and a Process Control Plan (PCP) was produced to meet MSER 2005 requirements. These tools identified and controlled critical steps, especially in the PE-8 handling and shaping process.

Overall, the primary role of the manufacturing engineer was to ensure an effective manufacturable design in a safe and cost-effective manner.

3.2. Communication with the team

Team communication was maintained through weekly meetings and a shared Microsoft Teams workspace. Live document collaboration eliminated version control issues and kept design data current.

Each team member managed their own technical tools (e.g. QFDs, DFMEAs) while reviewing inputs from others to ensure alignment. Weekly reviews were used to track progress, resolve cross-functional issues, and verify that interface points were addressed [9].

Daily contact windows were agreed for raising issues outside scheduled meetings. Sub-teams were formed to manage key interfaces: one between design and manufacturing, and another between manufacturing, safety, and disposal. These ensured continuous coordination across the system lifecycle.

Design-for-manufacture discussions addressed cavity geometry, fill method compatibility, and process constraints. These helped avoid infeasible options reaching concept selection [10]. Melt-cast was ruled out due to the small Net Explosive Quantity (NEQ) and integration complexity,

with PE-8 extrusion selected as a more practical alternative due to charge size.

Figure 1 shows the team communication structure.

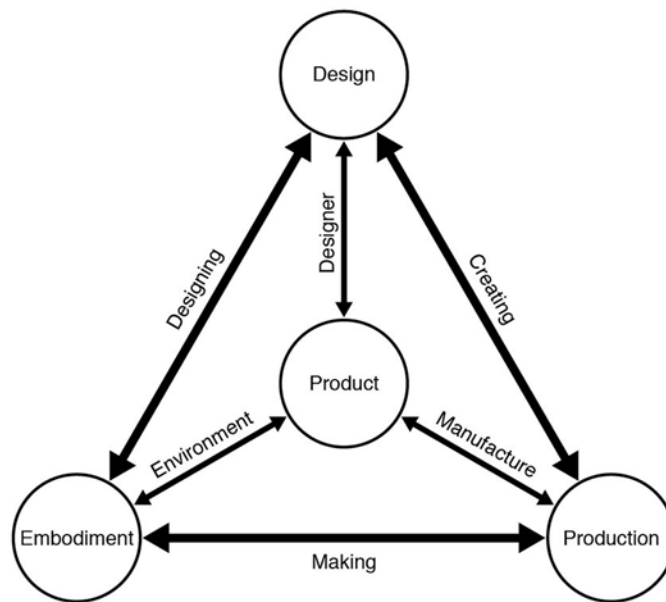


Figure 1 – Design-Manufacture Communication loop [11]

Figure 2 illustrates how manufacturing input led to the change in fill method.

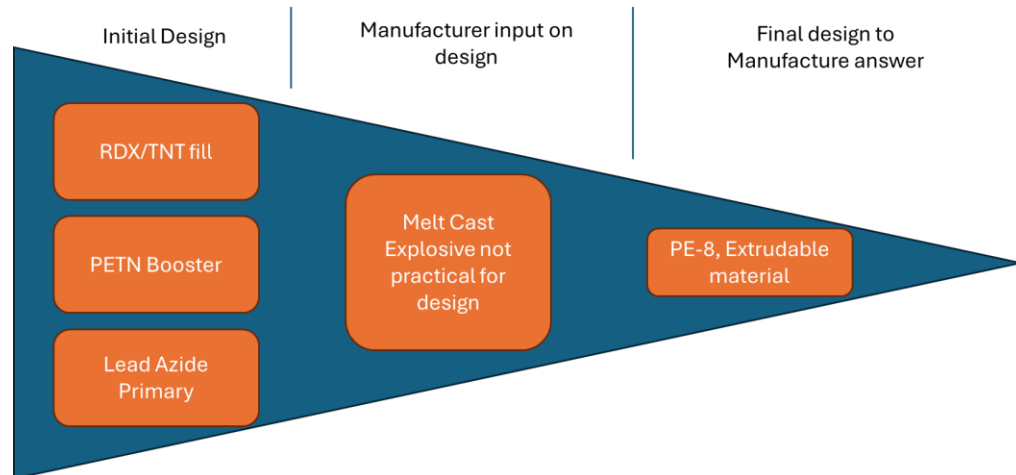


Figure 2 – Example Output of Effective communication routes

This approach ensured the final design remained within manufacturing and safety constraints throughout development.

3.3. Requirements and design

The objective set by the project brief was to develop an explosive device capable of neutralising a communications centre located on the second floor of a building, with minimal damage to surrounding areas. The system had to be accurately deliverable from at least 100m, while also being man-portable and safe to operate. A stretch target was included to disorient or immobilise room occupants rather than eliminate them.

These requirements were broken down into key functions through stakeholder mapping and functional analysis. The most critical needs were:

- Accurate delivery into the target room
- Penetration of external walls or windows
- Controlled and repeatable terminal effect
- Safe integration of explosive components
- Compliance with the MSER

These requirements were prioritised using a pairwise comparison (Figure 3) and fed into QFD1 (Figure 4) to determine the most important system functions. High-priority outputs included accurate assembly, safe delivery of the payload, and consistent target neutralisation. These functions guided the early design work.

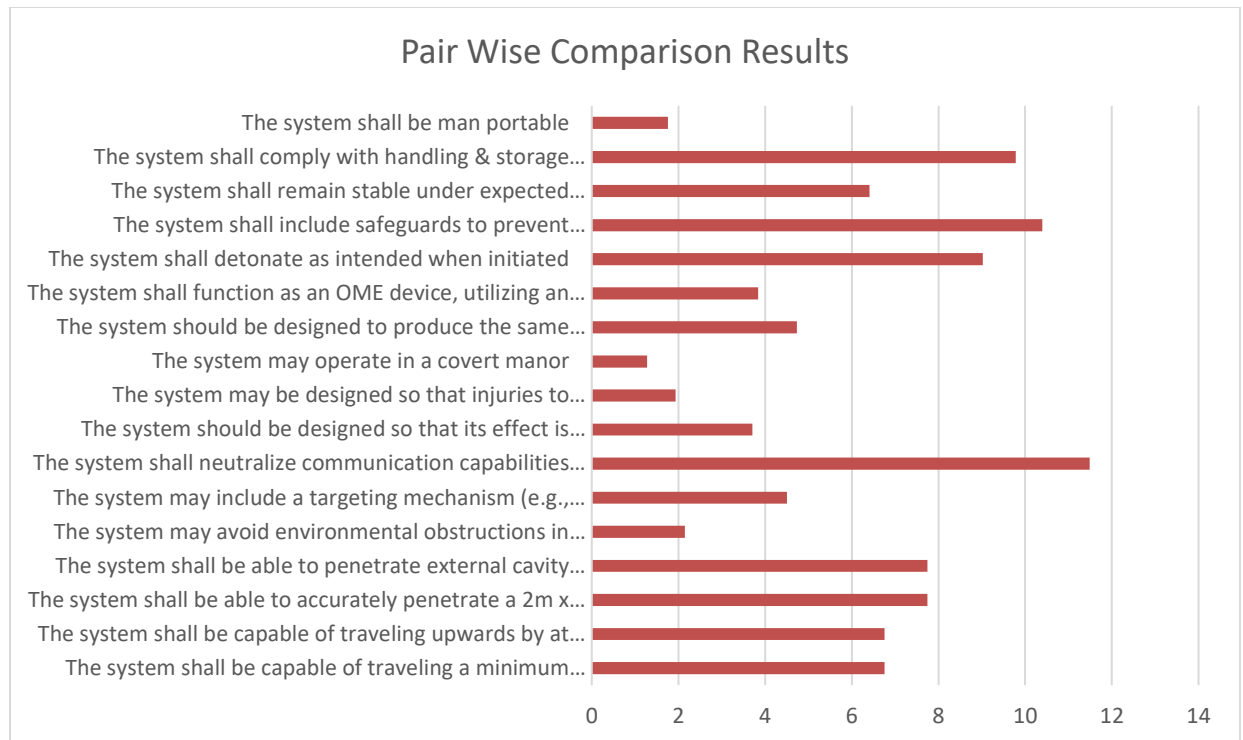


Figure 3 – Pairwise comparison results

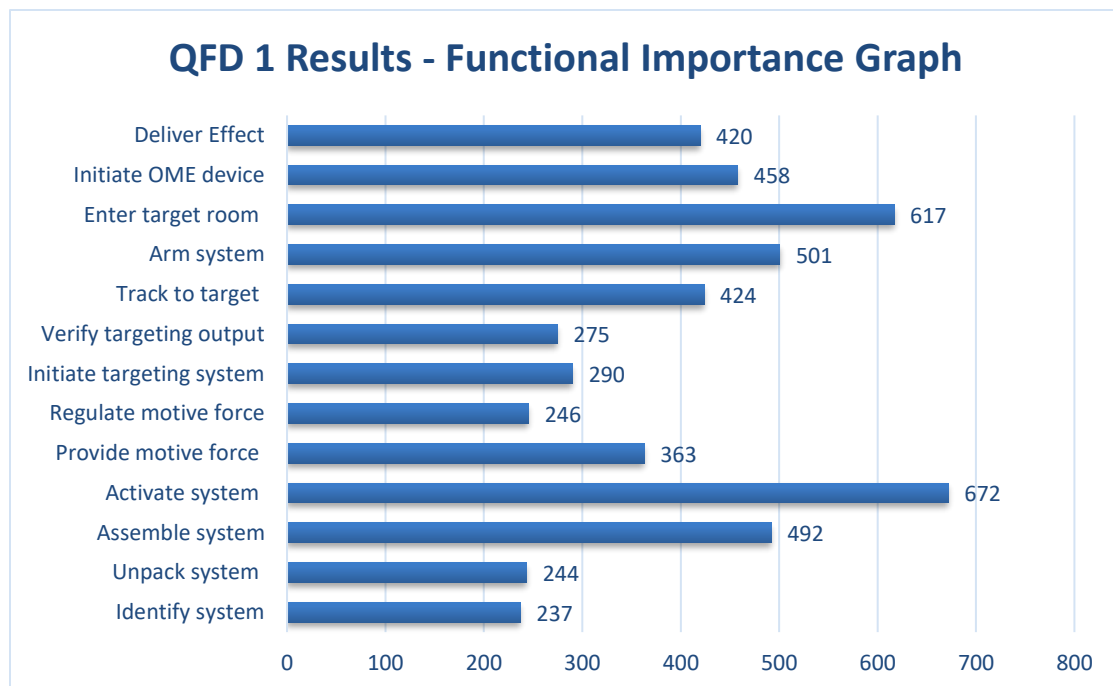


Figure 4 – QFD 2 Results

Three initial concepts were assessed: (initial designs compared with Bunker Defeat Munition [12])

- A single high-NEQ drone-delivered warhead
- A ground-fired warhead system
- A modular drone swarm with low NEQ charges (selected)

The third option was selected due to better control, reduced collateral risk, and compatibility with known manufacturing methods. A visual representation of the selected warhead design is shown in Figure 5.

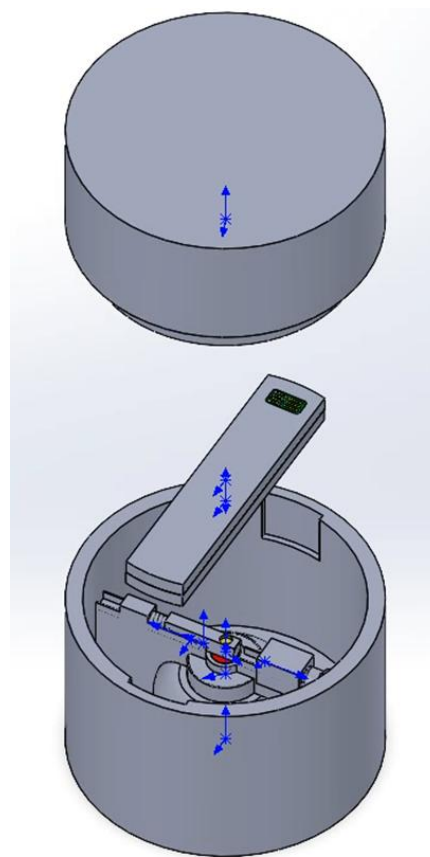


Figure 5 – Modular Warhead Concept Design.

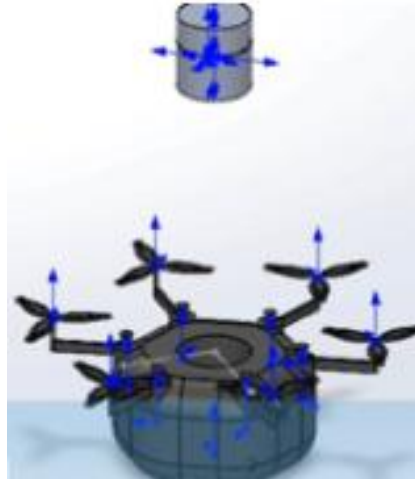


Figure 6 – Modular Warhead drone integration

4. Output to Team

4.1. Manufacturing Process Design book and outputs

The output to the design team was led through the creation of a structured manufacturing design book. This was built in parallel with key stakeholder communications and engineering activity to ensure the warhead sub-system could be physically realised while satisfying safety, performance, cost, and disposal requirements.

To begin this, a breakdown of manufacturing-specific customer requirements was derived using a SIPOC (suppliers, inputs, process, outputs, customers)-like method, visualised in Figure 7. These included metrics such as cost, surge capability, maintenance, quality, and safety, translated directly from stakeholder interviews and customer documents.

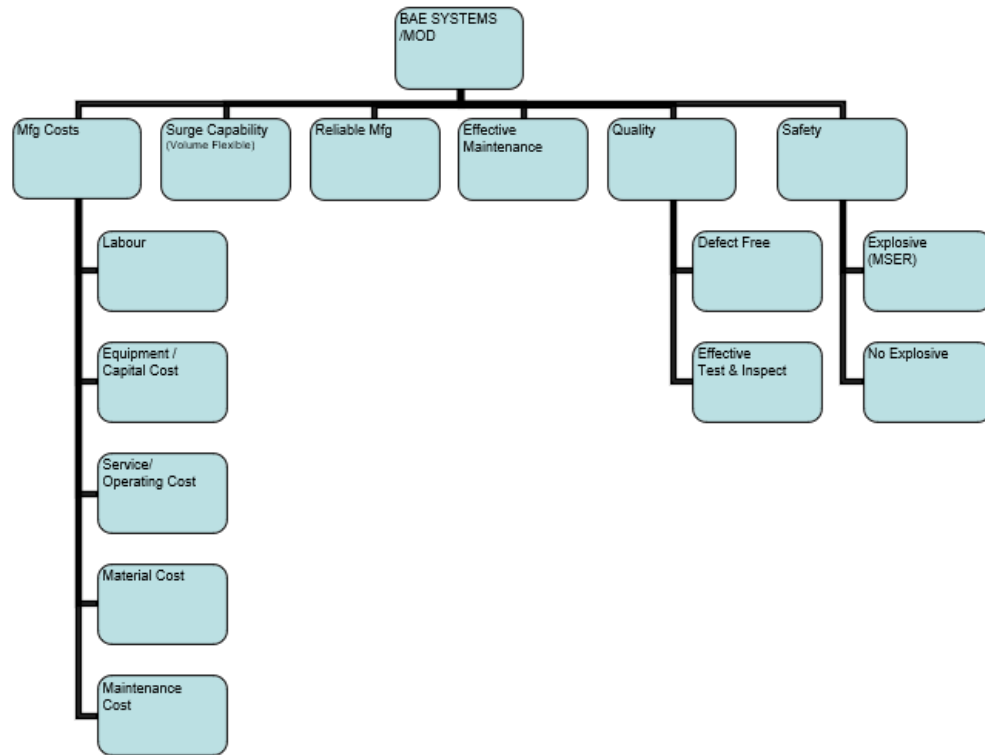


Figure 7 - Manufacturing-Specific Customer Requirements Tree

A full process flow (Figure 8) was created for the warhead sub-assembly, isolating the drone as a commercial off-the-shelf (COTS) item. This reflected team expertise, which was focused on warhead development. This flow formed the basis of the DfM analysis.

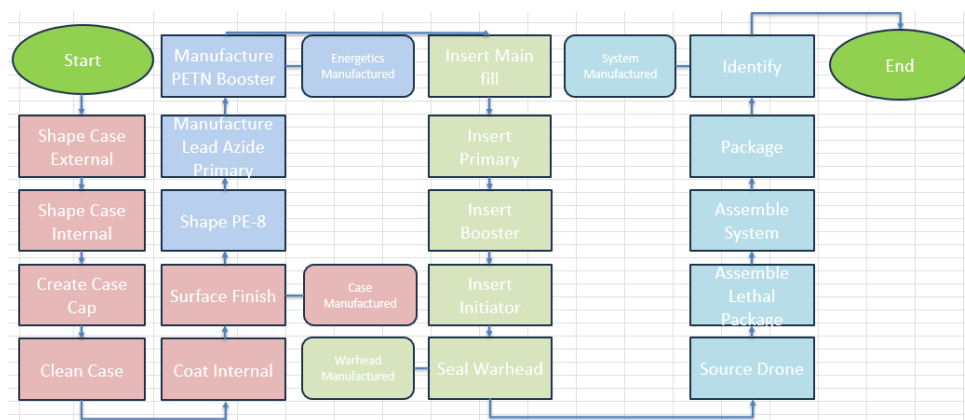


Figure 8 – Warhead Manufacturing Process Flow

Each stage was then assessed in a pairwise format (Figure 9), allowing the team to determine which processes carried the highest strategic importance to the final output. This pointed to shaping PE-8, initiating elements, and warhead sealing as key focus areas.

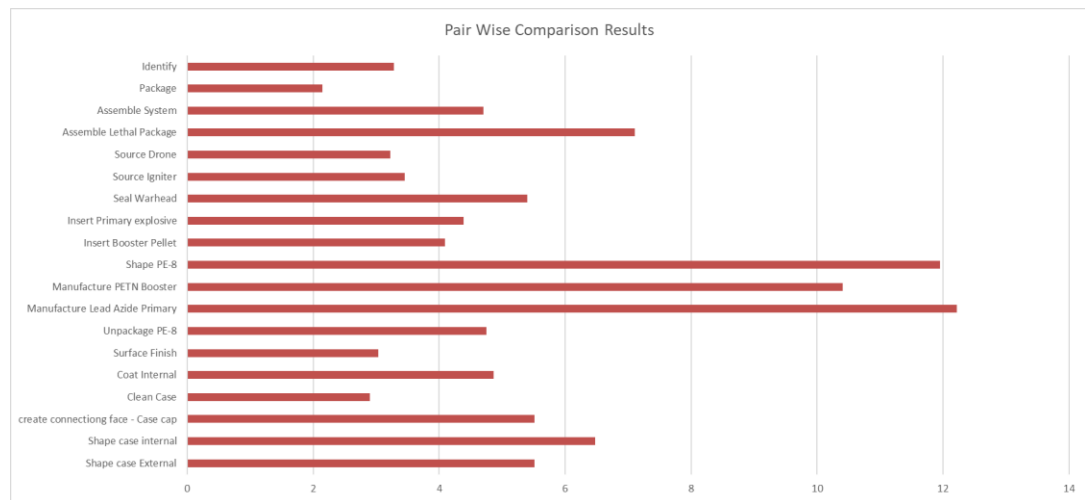


Figure 9 – Pairwise Comparison of Warhead Manufacturing Steps

To link process steps to customer requirements, a manufacturing-focused QFD1 was completed (Figure 10). This highlighted the importance of PE-8 shaping, insertion, and sealing processes due to their role in delivering effect, satisfying safety requirements, and enabling production repeatability.

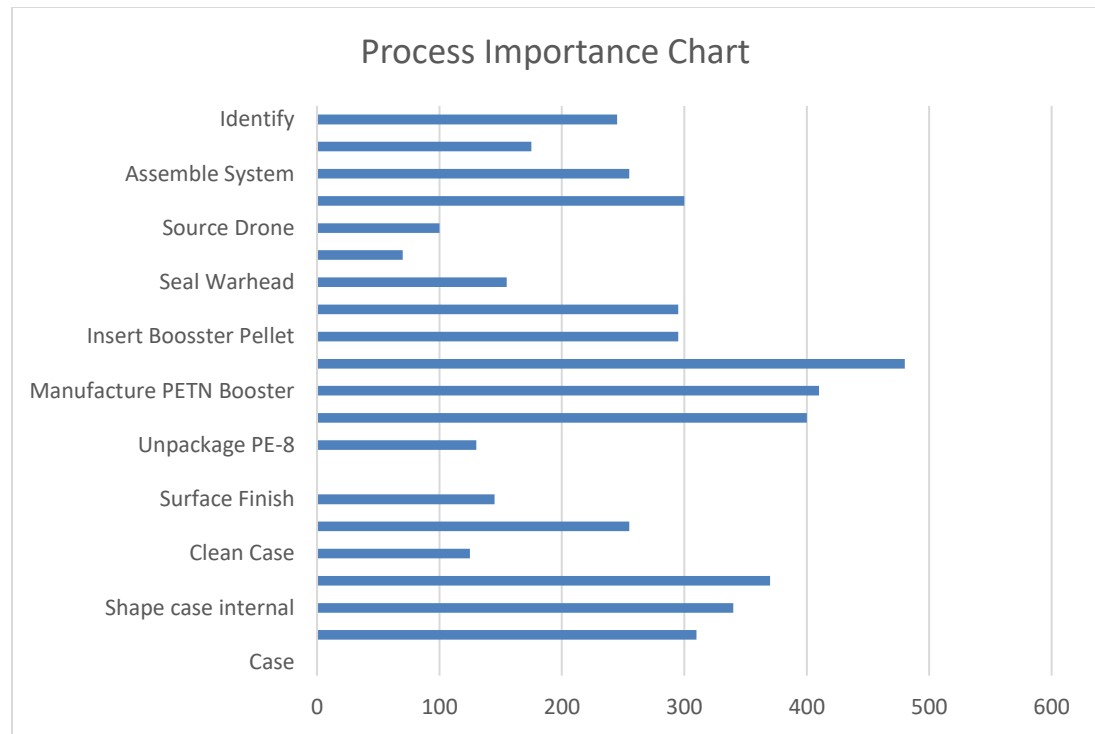


Figure 10 – Manufacturing QFD 1 Results

Feasible means to conduct the critical processes were then evaluated via a process-level Function Means Analysis (Figure 11). This identified extrusion as a viable shaping method and ruled out pressing due to detonation risk in small NEQ operations.

Function	Means				
Case					
Shape case External	Manual Lathe	CNC Mill	5 Axis CNC	Manual Mill	CNC Lathe
Shape case internal	Manual Lathe	CNC Mill	5 Axis CNC	Manual Mill	CNC Lathe
create connecting face - Case cap	Manual Lathe	CNC Mill	5 Axis CNC	Manual Mill	CNC Lathe
Clean Case	Ultrasonic Bath	Brush and Blow	Bath clean	Vacuum	
Coat Internal	Line	Plastic	PTFE	Polyethylene	
Surface Finish	Grind	Mill	Machined Finish		
Fill					
Unpackage PE-8	Hand				
Manufacture Lead Azide Primary	Cast Curing	Pressing	Extrusion		
Manufacture PETN Booster	Cast Curing	Pressing	Extrusion		
Shape PE-8	Hand Shape	Extrude	Press		
Fit Booster	Hand Assembly	Robotic Assembly	Push Fit		
Fit Primary	Hand Assembly	Robotic Assembly	Push Fit		
Seal Warhead	Lootite	PTFE			
Source Igniter	COTS				
Source Drone	COTS				
Assemble Lethal Package	Hand Assembly				
Assemble System	Hand Assembly	Robotic Assembly			
Package	Wooden Box	Metal Container	Foam Inserts	Antistatic bag	Bubble Wrap
Identify					

Figure 11 – Process Function Means Evaluation

Manufacturing QFD 2 (Figure 12) quantified which process steps were most influential in delivering the design requirements. Results supported the initial idea to adopt extrusion, and reinforced the priority of handling, pellet uniformity, and inspection.

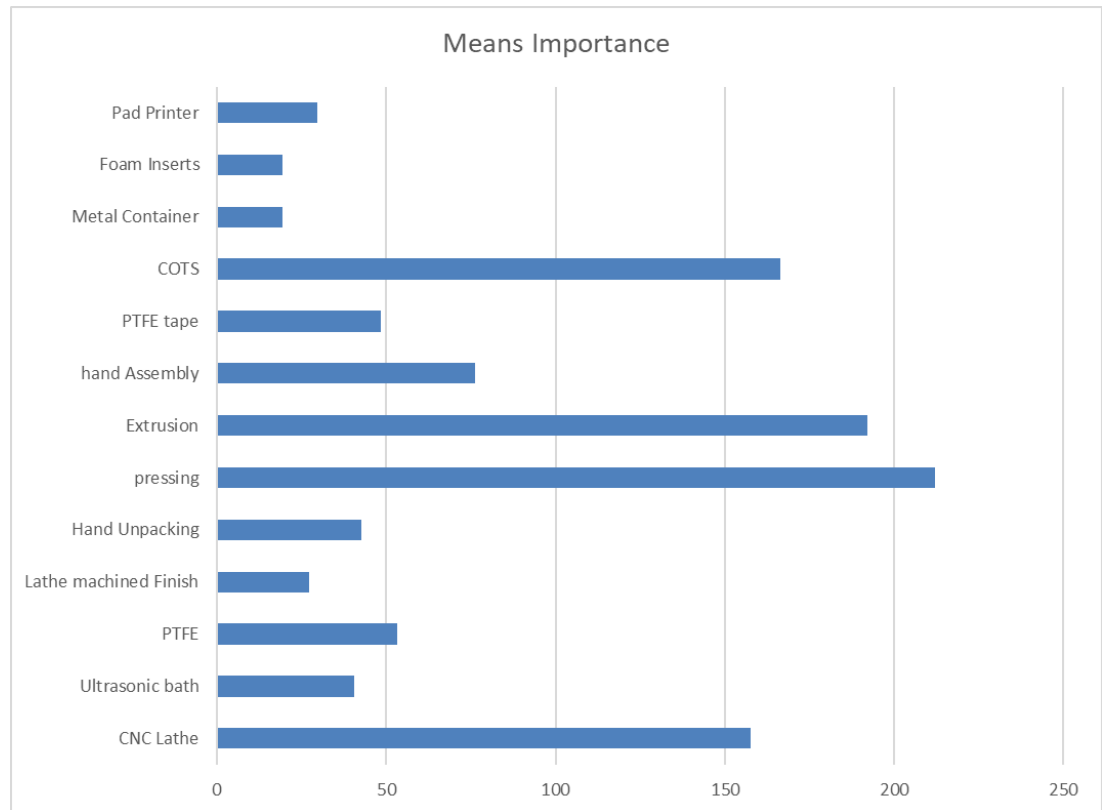


Figure 12 – Manufacturing QFD 2 Importance Scores

The PFMEA was then used to ensure that the manufacturing route would satisfy safety obligations under MSER 2005. This was done by reviewing each process for risk severity, occurrence, and detectability, with high-risk steps passed through into PCP development.

Operation No.	Operation Description	Failure Mode	Effect of Failure	RPN
13	Lubricate with approved dry film lubricant	Too much lubricant	Contamination of explosive material	48
10	Ensure Extrusion Drum grounding cable is secure	Grounding cable damaged	Electrostatic discharge → potential ignition	45
11	Inspect Extruder Screw Ram	Screw ram damaged	Pellet inconsistency; risk of future contamination	45
14	Perform dry test spin	Screw ram moves too quickly	Overpressure, machinery damage, extrusion instability	32
18	Verify temperature control	Temp control non-functional	Uncontrolled heating; explosive instability	30
8	Inspect Extrusion Drum	Drum contaminated	Product contamination or cross-batch reactivity	30
9	Check Extrusion Drum for moisture	Moisture present	Instability in fill; pre-initiation hazard	30

Figure 13 – PFMEA Summary Table

The resulting PCP, shown in Figure 14, focused on the high-risk process areas defined in the PFMEA and added tangible controls through

inspection, training, and Standard Operating Procedure (SOP) enforcement.

Critical Step	Description	Reason for Criticality
Grounding Cable Inspection	Ensure electrical grounding is intact and verified before operation	Prevents static discharge → ignition (RPN 45)
Screw Ram Inspection	Assess for wear, residue, or scoring before use	Affects fill uniformity, introduces contamination risk (RPN 45)
Temperature Control Verification	Confirm thermal controls are operational and stable	Prevents thermal runaway or sub-spec fill behaviour (RPN 30)
Dry Film Lubrication Application	Apply correct volume of lubricant to ram	Excess lubricant can contaminate explosive material (RPN 48)
Extrusion Drum Inspection (Clean/Dry)	Ensure no moisture or residue present	Moisture introduces thermal instability, contamination (RPNs 30/30)
Dry Test Spin of Screw Ram	Confirm correct motion profile pre-extrusion	Prevents pressure anomalies or mechanical failure (RPN 32)

Figure 14 - PCP Overview of Critical Controls

To visualise the full set of administrative controls that underpin the safe operation of the extrusion process, the five critical enablers were highlighted: SOPs, checklists, training, preventative maintenance, and independent inspection (Figure 15).

Op No.	Operation Description	Control Parameter	Control Method	Frequency	Reaction Plan
10	Ensure grounding cable is secure	Electrical continuity	Visual inspection	Pre-shift	Replace cable/clamp; reverify
11	Inspect Screw Ram for scoring	Mechanical integrity	Visual inspection	Pre-shift	Replace or escalate
13	Apply dry film lubricant	Lubricant coverage	Visual + touch test	Pre-shift	Clean and reapply lubricant
14	Perform dry test spin	Rotational smoothness	Manual test spin	Pre-shift	Inspect drive & bearings
18	Verify temperature control	Die head temp (°C)	Thermocouple sensor	Hourly during operation	Stop process; inspect heating system
8	Inspect Extrusion Drum	Cleanliness (internal)	Visual inspection	Pre-shift	Clean again; report if recurring
9	Check for moisture in drum	Internal moisture	Lint-free wipe test	Pre-shift	Dry drum; adjust HVAC or pause process

Figure 15 - Key Process Control Measures

These activities collectively formed the trilogy documentation—comprising the Process Flow Diagram, PFMEA, and PCP—aligned to explosive manufacture regulatory frameworks. They fulfilled the requirement for

process risk identification, mitigation, and control as per MSER 2005 and ISO 9001:2015.

Design alignment was maintained via QFD 3 and QFD 4 outputs (Figures 18 and 19), which linked product features such as homogeneity and dimension with manufacturing techniques and control parameters. These were supported by the manufacturing “What Why” matrix outputs (Noise factors and controls) and P-Diagram (Figures 16 and 17).

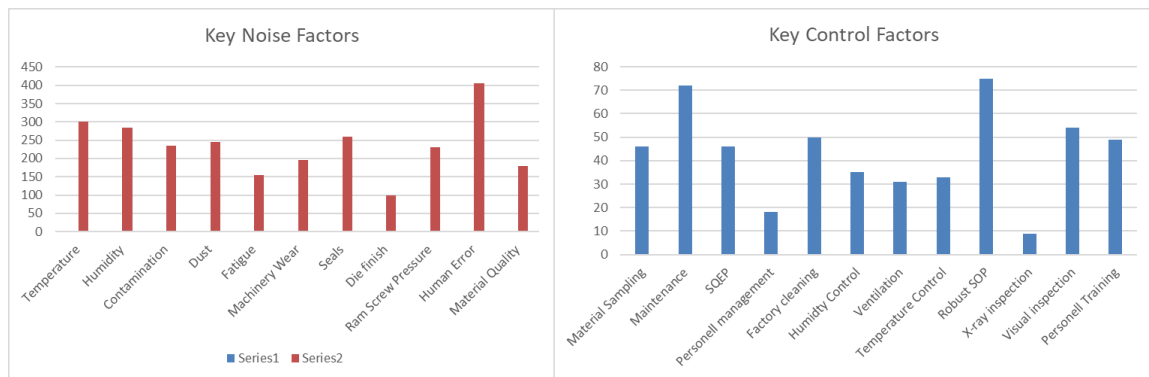


Figure 16 – “What Why” Outputs

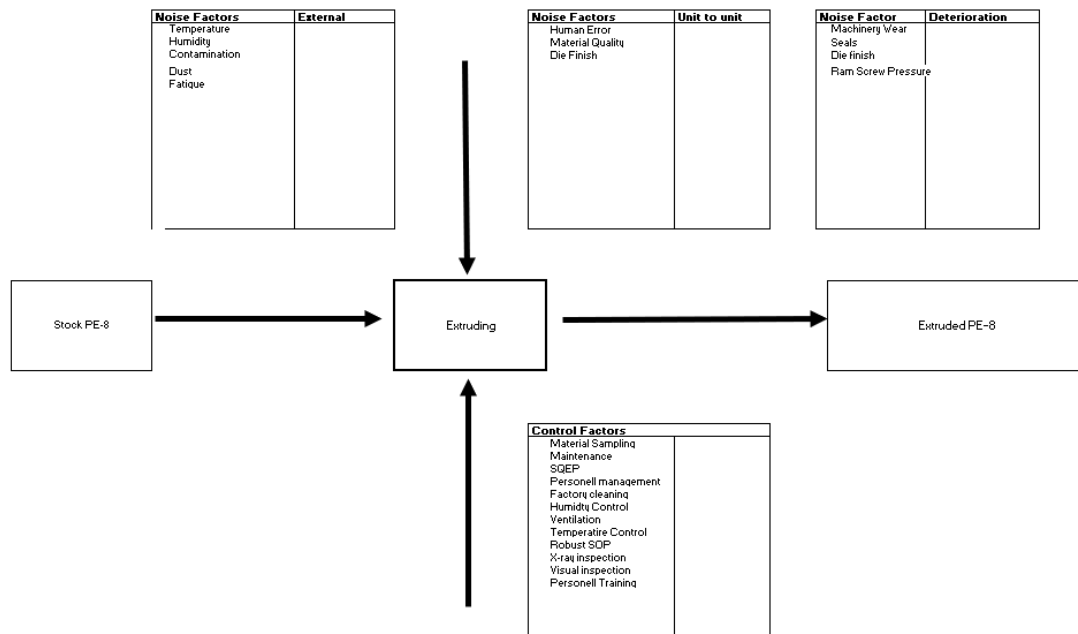
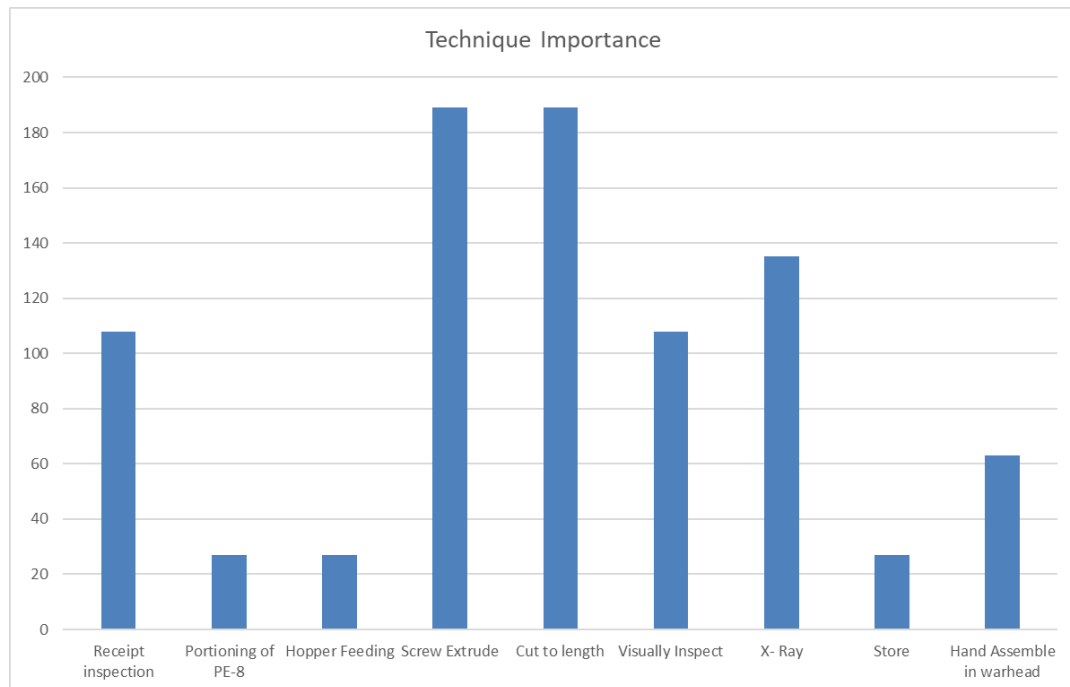
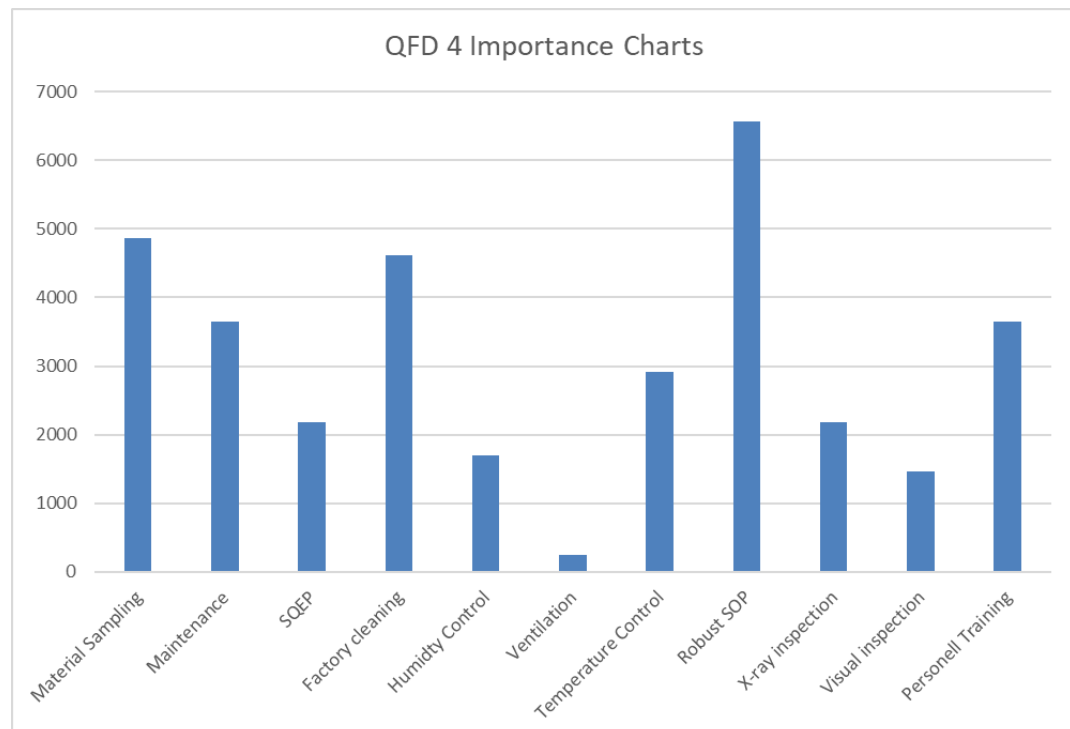


Figure 17 – P-Diagram**Figure 18 - QFD 3 Subsystem Design Feature to Process Mapping****Figure 19 - 4 Process Parameters vs Control Effectiveness**

These outputs were presented throughout the project at final team reviews to Solidify design decisions reasoning, supported by the early-stage

Function Means and regular design-manufacture feedback loops shown in Section 3.2. The design engineer remained in close contact, adjusting CAD geometry, fill cavity shape, and fill method to match the selected manufacturing tools.

4.2. Manufacturing Output to specific team members

To ensure the manufacturability of the design remained viable throughout development, the manufacturing engineer engaged directly with key stakeholders across the team:

- Design Engineer: Weekly collaboration was carried out to assess dimensional stack-ups, part tolerances and fill cavity access. Design iterations were reviewed to ensure material choices and integration methods could be supported with available processes and tooling. For example, the initial melt-cast concept was deprioritised due to poor feasibility for small NEQ geometries, and extrusion was proposed and validated through comparative analysis (Figures 9–10).
- Safety Engineer: Manufacturing process outputs, including SOPs, PFMEA and operator interface plans, were reviewed to ensure alignment with MSER requirements. Risk acceptance was confirmed for each stage, including handling of extrudable PE-8 and integration into the casing. Discussions with the safety engineer supported the

refinement of process steps such as operator sign-off points and environmental controls for static risk mitigation.

- Disposal Engineer: Although the delivery system was COTS, disposal engineer engagement ensured that the extruded pellet form would be compatible with existing in-house disposal methods (e.g. burning). This allowed upstream decisions—like pellet geometry and handling method—to support downstream disassembly and end-of-life neutralisation.

4.2.1. Design solution based on team input and answering customer needs

The final design solution was selected based on the customer requirements (figure 20) and the inputs from each team member (design book).

Ref	Requirement Description	Originator	Category	Manufacturing Implication
R1	The system shall be capable of traveling a minimum distance of 100 meters to reach the target.	Customer	Accuracy	Requires consistent mass and aerodynamic profile.
R2	The system shall be capable of traveling upwards by at least two stories (~8 meters) to reach the second-floor target.	Customer	Accuracy	Requires structural robustness and drone lift capability.
R3	The system shall be able to accurately penetrate a 2m x 1m window.	Designer	Accuracy	Requires controlled mass, geometry, and trajectory stability.
R4	The system shall be able to penetrate external cavity block wall to enter the designated room.	Designer	Accuracy / Effectiveness	Requires adequate charge performance and fill geometry precision.
R5	The system may avoid environmental obstructions in path to target.	Designer	Accuracy	Minimal manufacturing impact; affects drone flight path planning.
R6	The system may include a targeting mechanism (e.g., laser guidance, GPS, or inertial navigation) to improve accuracy over the required range.	Designer	Accuracy	Requires interface compatibility and modular mounting features.
R7	The system shall neutralize communication capabilities within the entire 10m x 8m x 4m target area.	Customer	Effectiveness	Requires consistent fill quality and detonation performance.
R8	The system should be designed so that its effect is limited to the target room and does not impact adjacent rooms.	Customer	Effectiveness	Requires controlled NEQ, directional charge shaping, and containment.
R9	The system may be designed so that injuries to occupants are minimised.	Customer	Effectiveness / Safety	Further drives NEQ reduction and precision targeting.
R10	The system may operate in a covert manor.	Customer	Signature Management	Requires low-profile, lightweight payloads and compact assembly.
R11	The system should be designed to produce the same effect each time it is deployed under identical conditions.	Designer	Repeatability	Requires strict process control, cavity fill accuracy, and assembly consistency.
R12	The system shall function as an OME device, utilizing an explosive event to achieve the desired effect.	Customer	Explosive Function	Requires qualified explosive fill, safe handling, and validated initiation systems.
R13	The system shall detonate as intended when initiated.	Designer	Explosive Function	Requires integration checks and initiation system QA.
R14	The system shall include safeguards to prevent accidental initiation during its lifecycle.	Designer	Safety	Requires ESD control, inert handling stages, and verified safety interlocks.
R15	The system shall remain stable under expected environmental conditions.	Designer	Safety	Requires environmental monitoring during fill processing and packaging.
R16	The system shall comply with handling & storage regulations.	Designer	Compliance	Requires use of REACH-compliant materials, safe packaging, and appropriate labelling.
R17	The system shall be man portable.	Designer	Logistics	Limits total mass; promotes modular build and sub-assembly handling.

Figure 20 - Full Requirements List based on Customer Brief

The warhead used pre-formed PE-8 explosive pellets contained within a shaped cavity, allowing for precision effect delivery with a reduced

NEQ. This supported the brief objective to neutralise the communications centre with minimal collateral damage, achieved by limiting blast radius and enabling controlled deployment through a drone entry point.

The COTS drone was selected to reduce design burden and focus technical scrutiny on the warhead subsystem — the area carrying the highest manufacturing and regulatory complexity. This approach allowed detailed process control to be established early, with compliance assured through alignment with MOD safety expectations.

Manufacturing constraints and DFMEA outputs (Figures 8, 15) led to the exclusion of melt-cast fills in favour of extrusion-based pellet manufacture. This reduced variability, improved handling safety, and enabled repeatable integration into the warhead casing.

The final solution met the key brief requirements including target room neutralisation (R7), effect containment (R8), and safe, repeatable deployment (R11–R15), and was supported throughout by justified outputs from the manufacturing design book. The outcome was a functionally sound, regulatory-aligned design that could be reliably delivered within real-world constraints.

5. Presentation, reflection and feedback response

During the presentation, the manufacturing contribution was focused on clearly demonstrating that the design was not only conceptually valid but also practically manufacturable under MOD regulatory expectations. Feedback from the panel and audience highlighted several positive elements, such as the logical layout of the slides, confident delivery, and strong linkage between the manufacturing process and the overall system functionality.

The audience appreciated the clarity and structure of the manufacturing content, particularly how the process was simplified using visual flows and design book outputs. The slides ensured the audience understood the trilogy methodology (Process Flow, PFMEA, and PCP), though time constraints limited how deeply each area could be explored. The full presentation slide deck is provided in Appendix 2 for reference.

Time management was a key area for improvement. While the manufacturing section was well-prepared to go into further detail on modular payload design and integration methods, earlier sections ran over their allocated time. This resulted in condensed delivery, particularly for the COTS payload interface and final process controls. Better timing coordination between team members would have enabled a more balanced depth across all content.

Delivery was confident, with good audience interaction. However, one observation from the feedback was that occasionally the presenter turned to the screen to point out details, this disrupted audience engagement. A recommendation for future delivery would be to use a laser pointer or click-through highlighting to avoid breaking eye contact and keep delivery more fluid.

The table below outlines the key feedback and questions raised during and post presentation, along with specific responses or lessons to address them in future work.

Feedback / Question	Response
Liaison with drone manufacturer?	Not directly addressed during the presentation. This query could have been avoided with a slide noting that the drone was a COTS item with no supplier collaboration planned.
How do you get clearance onto the drone?	More visual explanation or an annotated CAD image of payload clearance would have clarified this. A pointer tool could have assisted in guiding the audience.
What happens with returns from Ops?	Disposal assumptions were not clearly explained in presentation format. This should have been briefly summarised as “modular removal and compliant disposal.”
Slide visual consistency	Slide consistency was good overall, but deviations in colour schemes (e.g., white text on pale colours) affected legibility. A standardised theme will be used going forward.
Trilogy – explain it in the report	Trilogy was mentioned but not defined clearly in presentation. A clearer title slide and brief verbal outline would have helped audience understanding.
Good pace and open delivery (Jenni)	Confidence and volume were received well. However, movement to the screen for pointing broke eye contact. Future improvement includes use of a laser pointer or click-to-highlight to maintain audience engagement.
Some slides lacked technical depth	Time limitations forced condensing of detail. Better internal time management would ensure each section receives full planned coverage.
Team collaboration well demonstrated	Each section referenced others, and a good narrative flow was maintained. This was highlighted positively and should be kept in future group delivery.

Figure 21 – Presentation Specific Feedback Response

6. Reflection and after-action review – full program

The overall project structure allowed for a full lifecycle simulation — from customer brief through to conceptual design and manufacturing feasibility.

Manufacturing was engaged early in the process and was critical to identifying a viable route for explosive integration. The use of tools such as the design book, QFD matrices, and PFMEA enabled traceable, defensible decision-making.

6.1. What went well:

- Strong alignment between manufacturing and design ensured that early concepts evolved into feasible, testable solutions.
- Regular team meetings and structured sub-group reviews (e.g. manufacturing-design and manufacturing-disposal) meant risks could be escalated and discussed quickly.
- Use of collaborative platforms (e.g. Microsoft Teams) allowed version control, live updates, and shared access across the team.
- Manufacturing-specific outputs such as the PCP, PFMEA, and QFDs aligned with regulatory expectations and guided system-level decisions.

6.2. What could have been improved and how

Issue	How It Could Have Been Improved
No formal test engineer role; reliance on assumptions for key performance validation (e.g., drone vibration survivability, fill behaviour)	A test and trials SME could have been appointed early to own assumptions related to environmental tolerance, physical interface loading, and payload survivability. Alternatively, an “Assumption Register” shared across roles could track high-risk unverified assumptions and prioritise validation points for future prototyping.
Late-stage design changes did not always align with the manufacturing feasibility envelope (e.g., fill form factor or integration approach)	A formal change control process should be implemented for future projects. This would include manufacturing sign-off on any design change that affects geometry, material, or integration route, especially where tooling, tolerancing, or operational steps are affected.
No defined process for confirming assumption ownership and risk	Alongside the Assumption Register, each assumption should be linked to a specific mitigation step, stakeholder, and verification milestone. A simple RACI matrix for assumptions would help clarify who validates what and when.
Some sections of the presentation overran, cutting content from other areas (e.g., manufacturing-drone integration)	A stricter internal run-through with hard time limits per role would prevent overrun. Slides should be pre-approved for scope and focus. Team members should be briefed to cut lower-priority material if time becomes constrained.
Lack of a final summary/conclusion slide to close the presentation	A designated team member should have responsibility for slide compliance (e.g., required sections, reference slides, system summary). Pre-presentation audits against the marking rubric would ensure completeness.
Absence of a formal presentation checklist	Creating a universal presentation checklist (layout consistency, references, timing, presenter order, handovers, slide transitions) would reduce missed expectations and ensure all assessment points are addressed.
Interface considerations with external components (e.g., drone rail mounts) were not fully demonstrated in the deck	Inclusion of a dedicated slide with annotated CAD showing the integration interface would have clarified this visually for the audience. Follow-up work should include CAD-based clearance, vibration, and mounting verification trials.

Figure 22 – problems and possible improvements

6.3. Lessons Learned

- Cross-role communication is essential to manage complexity in systems design. No individual role had complete system oversight, so mutual reviews were required to align manufacturing feasibility with performance and safety outcomes.
- The design book process was the backbone of technical integration, enabling traceability and weighting of decisions across stakeholder needs.
- Engaging manufacturing early in the process helped reject impractical fill options, and enabled safe, repeatable manufacturing routes to be developed in parallel with system-level design.
- Failure to formally manage design assumptions introduces risk. These need to be tracked and validated by the appropriate roles as the system evolves.
- Presentation clarity relies on more than good technical content; time management, visual clarity, and audience connection are critical, especially in multidisciplinary panels.

7. Conclusion

The project successfully demonstrated how integrated systems engineering approaches can be applied to develop a safe, compliant, and manufacturable warhead subsystem. From a manufacturing perspective, early involvement in requirement development, risk identification, and design feasibility ensured that the final solution met both stakeholder expectations and regulatory constraints.

Key manufacturing tools such as QFDs, PFMEA, and PCP were used to guide decision-making and validate that the PE-8 extrusion process was the most suitable manufacturing route. Close collaboration with the design, safety, and disposal engineers ensured that constraints around assembly, operator safety, and end-of-life handling were fully addressed within the selected solution.

The design solution aligned with the customer brief by enabling precise, low-NEQ payload delivery with minimal collateral impact, while being manufacturable using controlled, verifiable processes.

While the final output met the objectives set, the project identified opportunities to improve cross-role assumption management and time allocation in presentations. These insights will inform future team-based projects, particularly the need for proactive assumption tracking and tighter coordination in time-limited delivery environments.

Overall, the project provided valuable experience in applying systems thinking to manufacturing and reinforced the importance of early-stage collaboration, traceable tool use, and regulatory alignment throughout concept development.

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9. Appendix 1 – Gemba Visit

Gemba Visit Report

Gemba Visit Report – Salisbury Plain (Imber Village)

In Attendance:

- Development Team (All members)
- 2 Stakeholders
- 5 End Users

Objective:

To observe how end users engage with their existing weapon systems in an operational training environment, identifying challenges, risks, and potential areas for improvement in the new system development.

Observations:

During the visit, end users demonstrated their current system used to neutralize potential threats in an urban setting as part of a structured training exercise. The systems currently in use include:

- FGM-148 Javelin
- M141 SMAW-D

Both systems were observed in a realistic operational setting, demonstrating their compliance with both legal requirements and the mandatory performance criteria outlined in the customer's requirement set. During the exercise, both systems successfully achieved full target room destruction, including the intended communications equipment.

However, several key observations were made:

- The current systems were identified as overmatched for the requirement, causing significant collateral damage beyond the target room, affecting adjacent rooms and the floor below.
- The effect of the system was assessed as incompatible with life for any occupants in the target room and posed a significant risk of catastrophic injury to personnel in the surrounding structure.
- End users noted that between firing and impact, only seconds elapsed, meaning people in the target room had little time to react before the effect was delivered.

Key Insights from End Users:

Preferred Features in Current Systems:

- Fire-and-forget capability
- Single operator firing capability
- Two-person portability
- Soft-launch capability (*noted for improvement; see below*)
- Consistent terminal effect on target when a hit is achieved

Challenges Identified in Current Systems:

- Overmatch in urban environments, causing excessive damage beyond the intended target.
- IR seeker performance issues, leading to decreased targeting accuracy.
- Backblast hazard, which can pose risks to the firing team in confined spaces.

Conclusion:

Discussions with stakeholders and end users confirmed that a system more closely matched to the requirement would be preferable, reducing unnecessary damage to surrounding structures while still ensuring complete neutralization of the target. Stakeholders acknowledged that while minimizing reaction time in the target room is critical, achieving this does not necessarily require the system to be fully covert.

Next Steps:

Following the stakeholder engagement and Gemba visit, the refined requirement set (as per the requirement table for full details) will now guide the next phase of development through Quality Function Deployment (QFD1) and functional means analysis. The customer-driven requirements establish core performance expectations, while the designer-driven requirements, informed by operational insights, ensure practical feasibility and mission effectiveness.

10. Appendix 2 – Group Presentation

PROJECT PENTHUS

Rebecca Dingwall, Harry Grinstead, John James, Owen Miller
and David Tolhurst

PROJECT PENTHUS

INTRODUCTION

DT

Things to decide:

- Whos doing intro? – Owen/David
- We need to talk about inputs and outputs for trials
– black box approach – Talk about in each person's
specific area
- Rough time break up for each section – 5 min intro,
8 mins per person
- Where do we show a full sequence of operation for
the system ? – straight away
- Is it worth it to create a visual of the room in
solidworks to support project brief ? – Stretch for
Beccs if possible

Presentation Details

FF002 at 13:15 on 03/04/25

45 mins presentation
15 mins of questions

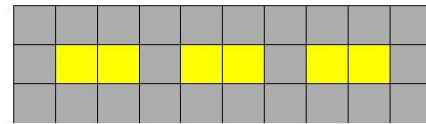
Project Penthus

Introduction

[Initials]

Project Brief

- Create an explosive device capable of neutralising a hostile communications centre, housed in a room within the second floor of an office block building. The design should be capable of accurate delivery into the room from a distance of at least 100m and the effect event should be such that collateral damage to adjacent rooms is minimised.
 - Describe the requirement demands from the project stake holders
 - Describe the likely requirements to be included by the stakeholder community in the procurement specification. What are the likely design trade-offs that may affect the mission in the field.
 - Propose options for meeting the requirements.
 - Propose designs describing:-
 - a. The functional sequence for the device and the proposed solutions for those functions,
 - b. A rationale for the selection on the chosen solutions,
 - c. Likely failure mechanisms and ways of mitigating them.
 - d. A method of manufacture including key QA activities
 - Describe a test programme to demonstrate the overall suitability of the proposed design and to identify and assess likely hazards.
- Room is 10m long x 8 m wide x 4m tall
 - The longer 10m wall is the outside wall. Other walls are internal
 - The outside wall has three windows 2m x 1m equi-spaced along the length of the wall
 - The room is accessed from a 3m wide corridor running along the opposite 10m wall by two standard doors, one at each end of the room. During operational periods, the doors are kept locked and barred from the inside.
 - The external walls are of rendered filled cavity block construction, internal walls are soft block constructed with plasterboard over baton facings.
 - Windows are double opening standard UPVC double glazed units
 - There are normally six operatives in the room operating at three terminals within the room.



Project Brief and requirement sets

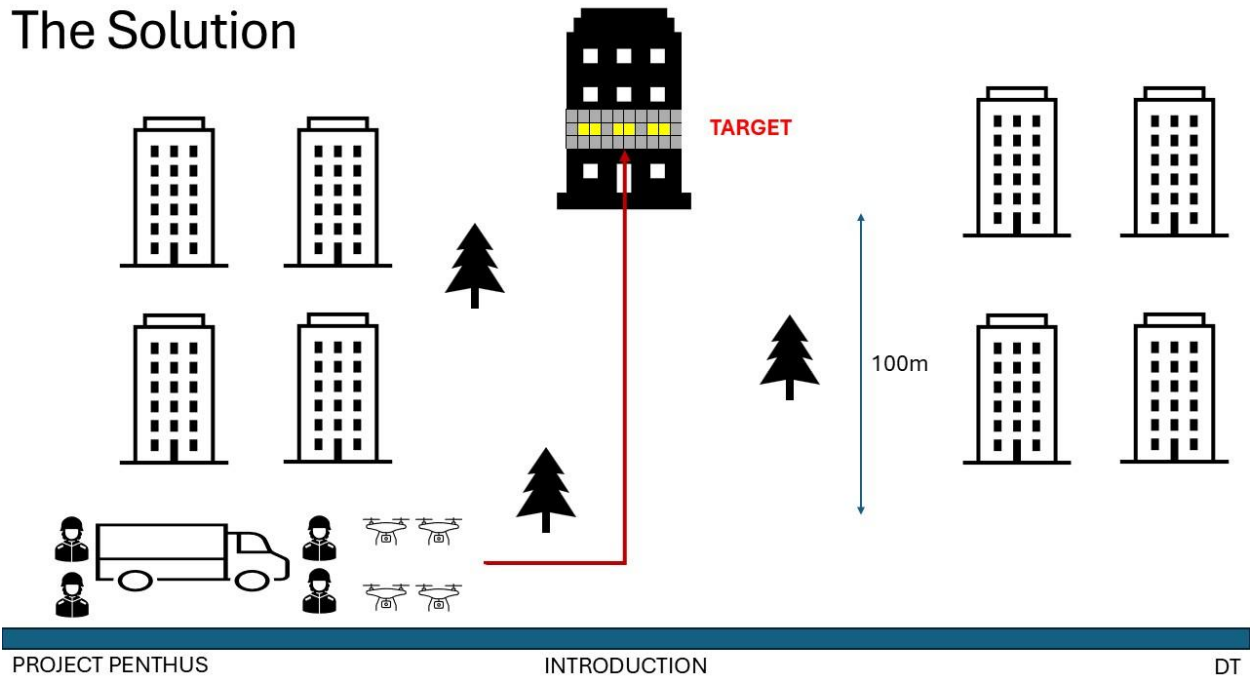
Key initial requirements:

- Neutralise comms centre with minimal structural or personnel damage
- Prefer disorientation over elimination of occupants
- Room: 10 × 8 × 4 m with 3 windows, 2 barred doors
- 6 operatives typically inside; standard block/plasterboard construction

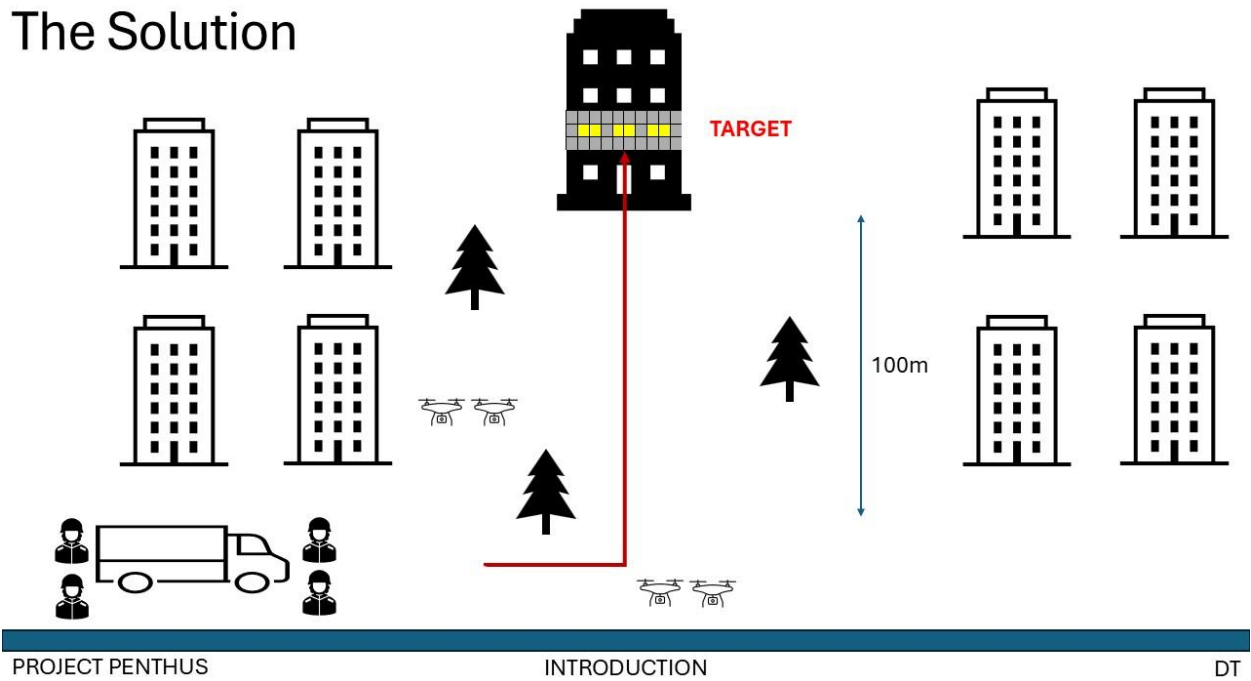
Stakeholders'/derived requirements meetings:

- Include fail-safes to prevent accidental initiation
- Support laser/GPS/inertial targeting for precision and obstacle avoidance
- Deliver repeatable effects
- Remain stable in storage and under environmental stress
- Be fully man-portable — no vehicle or crew required

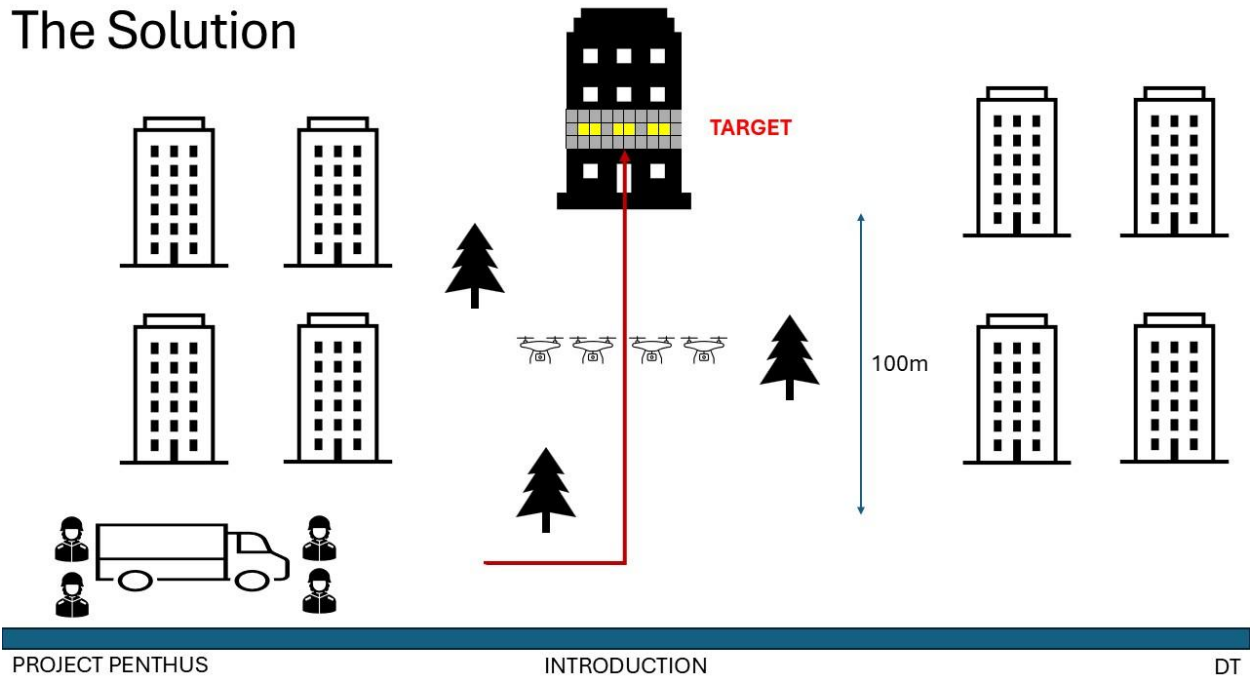
The Solution



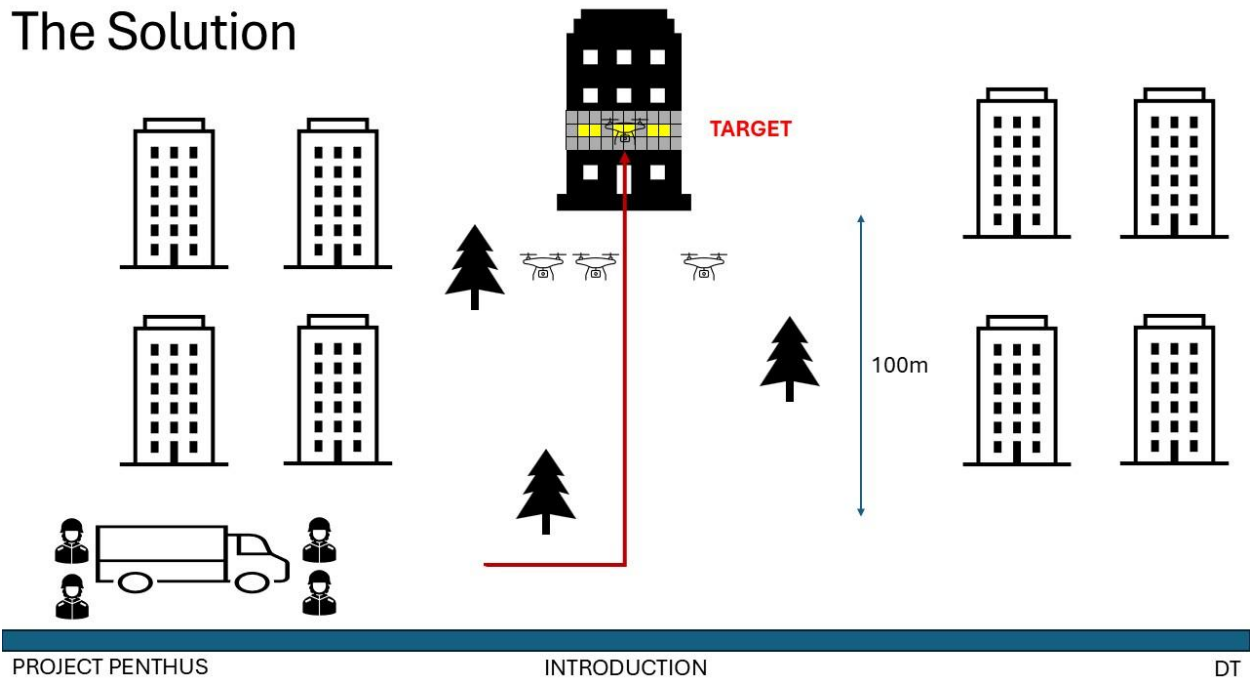
The Solution



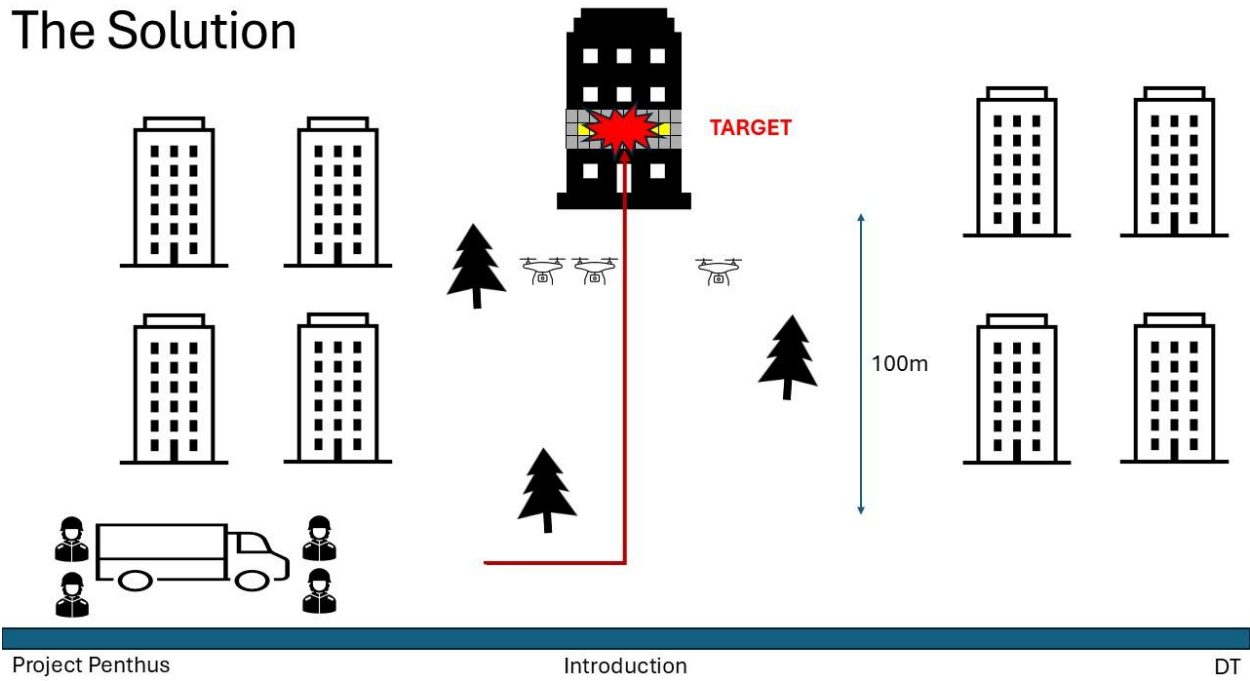
The Solution



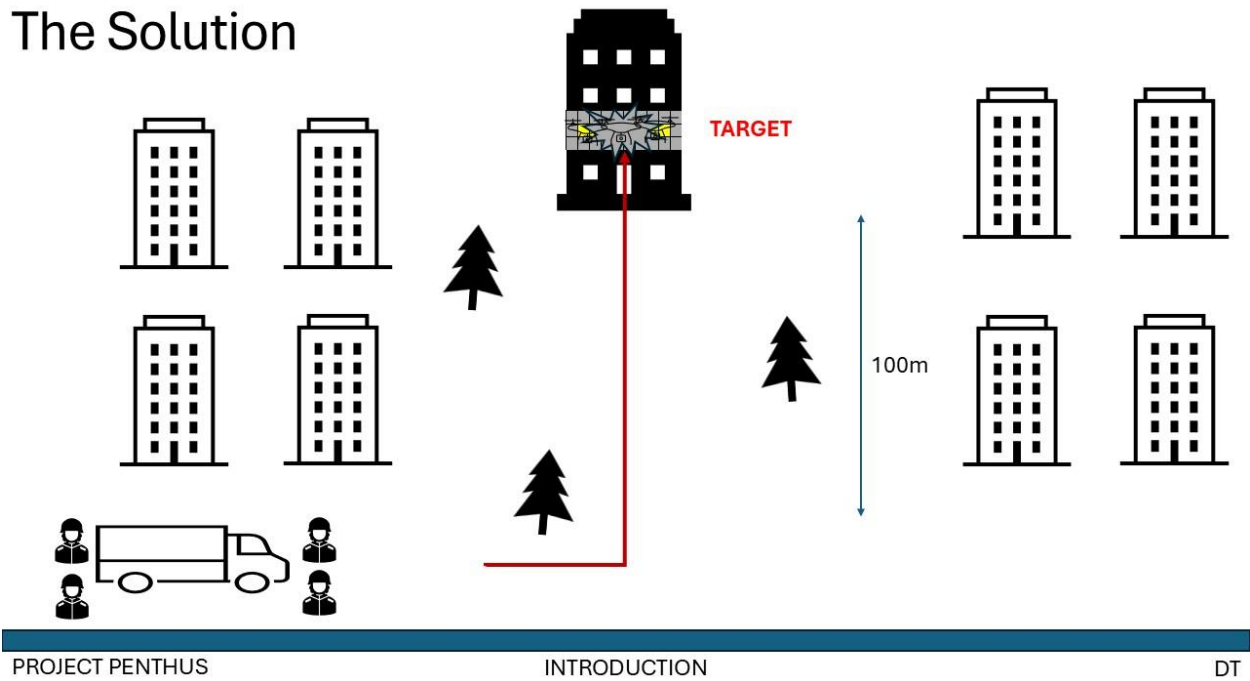
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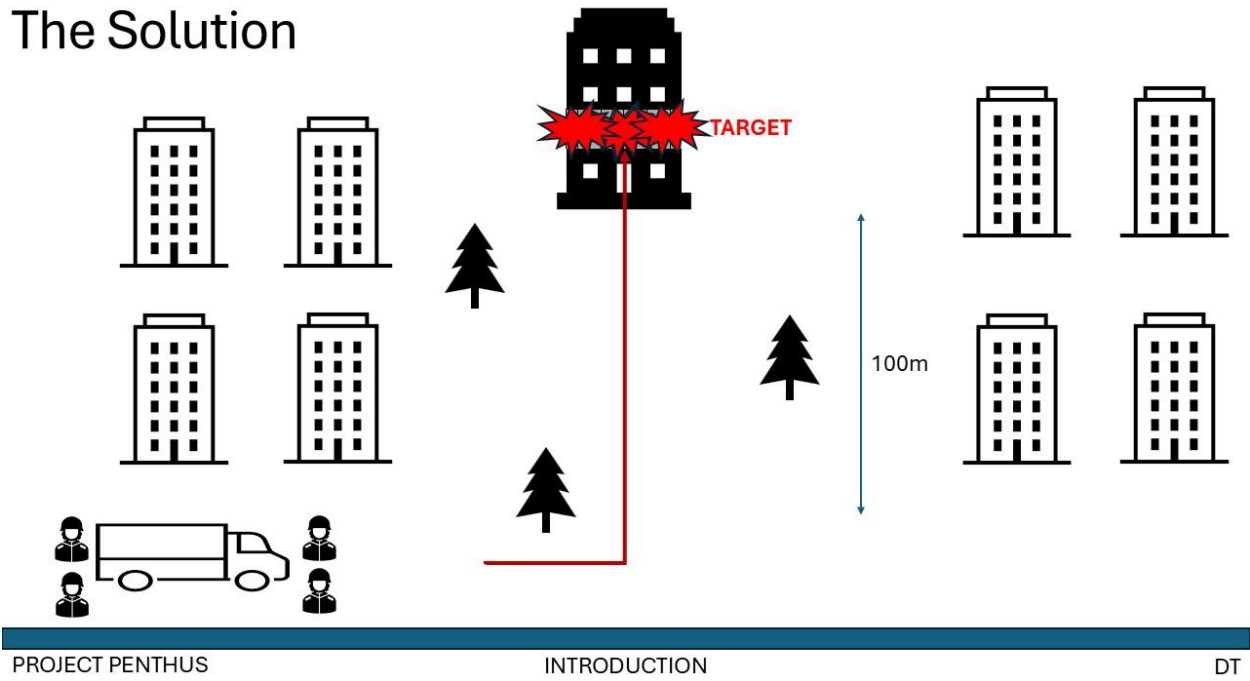
The Solution



The Solution



The Solution



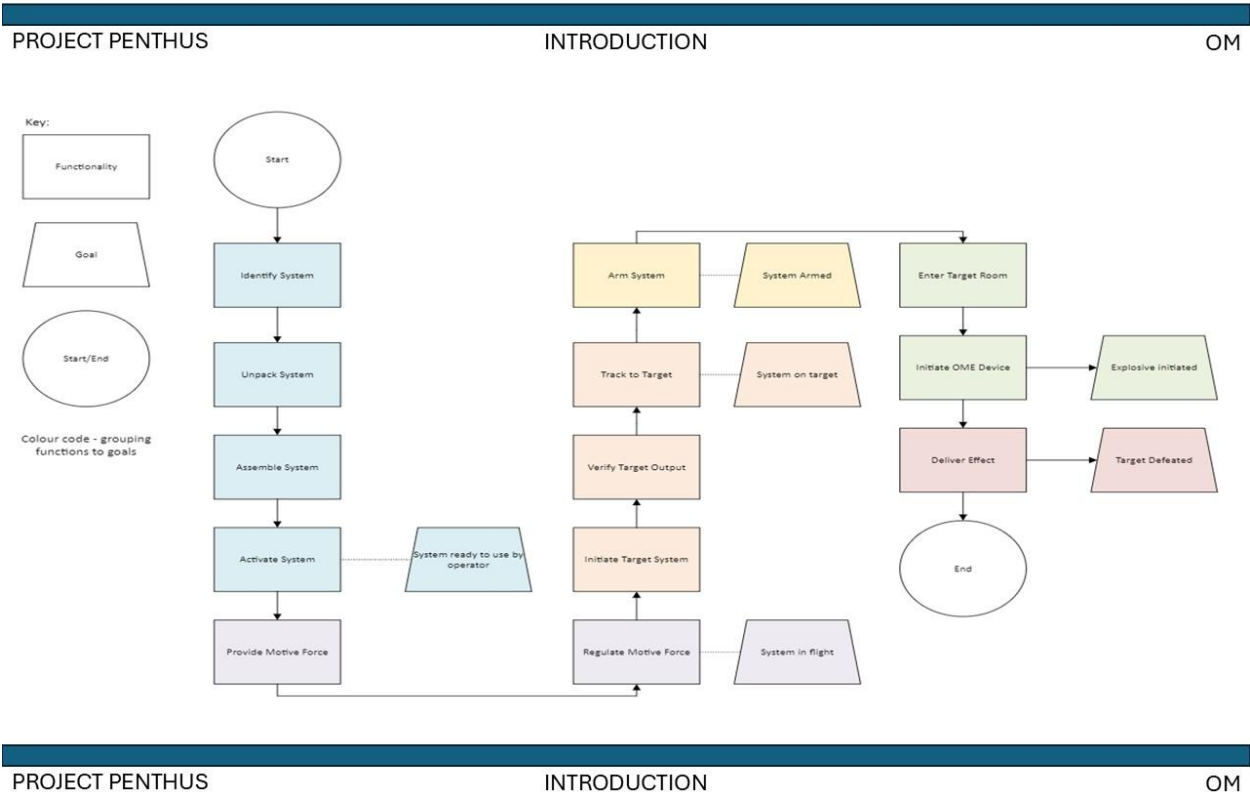
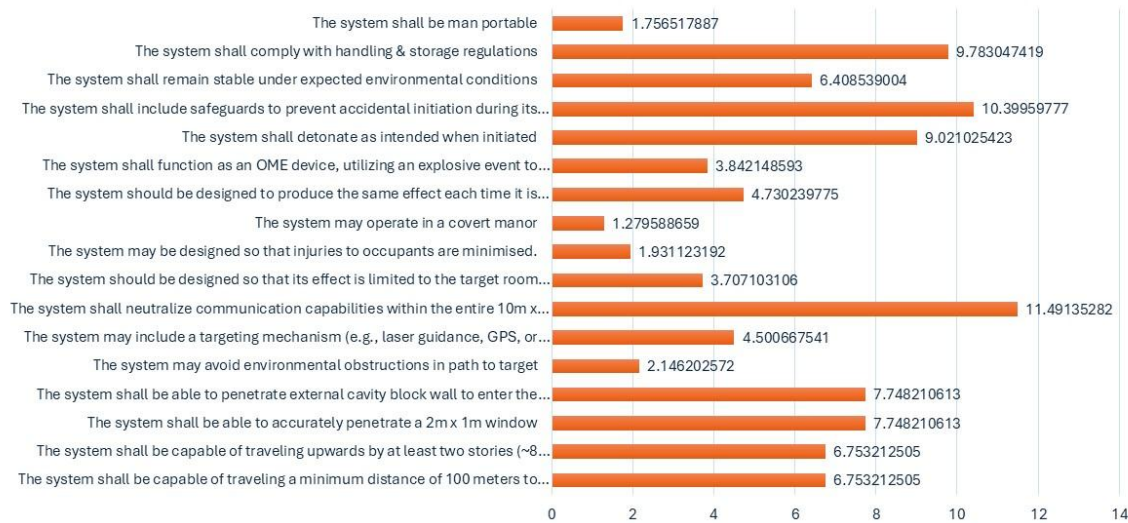
Team Roles

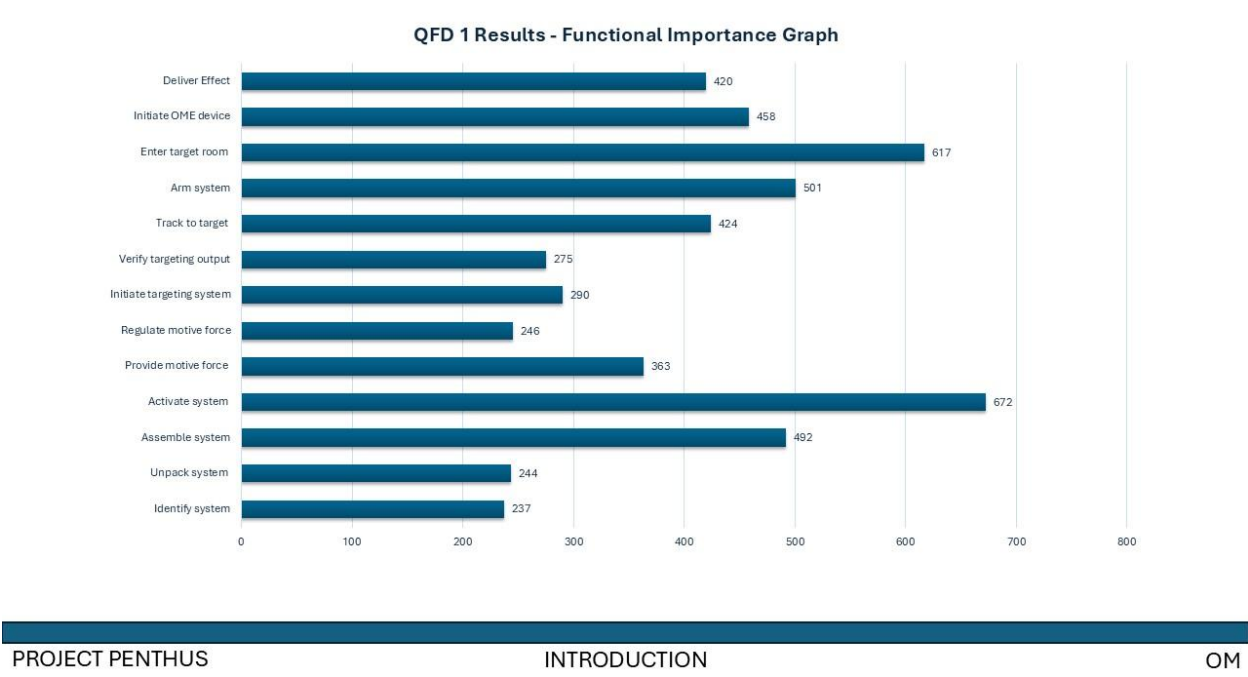
Requirements & Design	Technical Research and Development	Trials, Testing and Evaluation	Manufacturing	Disposal
Team Members	Team Members	Team Members	Team Members	Team Members
Bec Dingwall	Bec Dingwall	N/A	Owen Miller	John James
Harry Grinstead				
John James				
Owen Miller				
David Tolhurst				

Safety

Team Members	Harry Grinstead	David Tolhurst
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Pair Wise Comparison Results





Function Means Analysis

Function	Means														
Identify system	Operator Recognition	Colour Code	Digital Interface	RFID Tag	Barcode	QR code	AR Overlay	Dimension	Smartphone Application	Biometric Access	Mission Card	Markings	Labelling	Mechanical keying	Case
Unpack system	Manual Unpacking	prepack-ready-to-use	Quick Release	Pull Tab	pressure launched system	breakaway casing	Self Deploying container	Drop Pod	Tear away packaging	Collapsible unit	Locks	Magnets	pre-scored packaging	Case	
Assemble system	Operator Manual Assembly	Pre-assembled system	Snap fit	Tool-assisted	Self locking components	Magnetic coupling	Threads	Adhesive	Collapsible unit	Pin Hinges	Velcro	Compression fittings	Spring Loaded	Modular system	
Activate system	Switch	Wireless activation	Self activated (AI)	Proximity activation	Time delay	Kinetic	Environmental trigger	Biometric Activation	password	Key	Touchscreen	Voice	Magnetic trigger	Shock	
Provide motive force	Thrown	Rocket	Mortar	Gun Launched	Helicopter	Tracks	Wheels	Pneumatic Launch	Spring	Glide Assisted	Quadcopter				
Regulate motive force	Throttle	Variable Thruster	Aerodynamic control surface	Gyroscope	Program flight path	Thrust vectoring	parachute	Air brakes	Electric motor variation	Energy recovery system	one off propulsion				
Initiate targeting system	optical sighting	Laser Designator	GPS	Radar	Infrared	RF signal	Artificial Intelligence	Object recognition	Look on after launch (LOAL)	LIDAR	Operator designation	Electromagnetic emissions tracking			
Verify targeting output	Visual	Heads Up display	IRI	Radar	Optical verification	AI	GPS coordinate verification	Inertia	Pre strike authorisation	Less					
Track to target	Laser	GPS	Gyroscopic	Optical Tracking	Operator Controlled	Infrared	Radar homing	RF tracking	AI	Terrain effect flight	Beacon homing				
Arm system	Switch	Remote arming command	Time delay	Environmental trigger	proximity	GPS	Accelerometer	Optical	RF detection						
Enter target room	Shape charge penetration	HE Blast	KE penetration	Thermobaric Charge	EFP	reinforced nose cone	spring loaded spike								
Initiate OME device	Impact fuze	Timed Fuze	Proximity Fuze	Operator Command detonated	Barometric Fuze	Bridgewire									
Deliver Effect	Blast	Frag	EMP	KE Penetration	Shaped Charge	Thermobaric	Flechette								

PROJECT PENTHUS

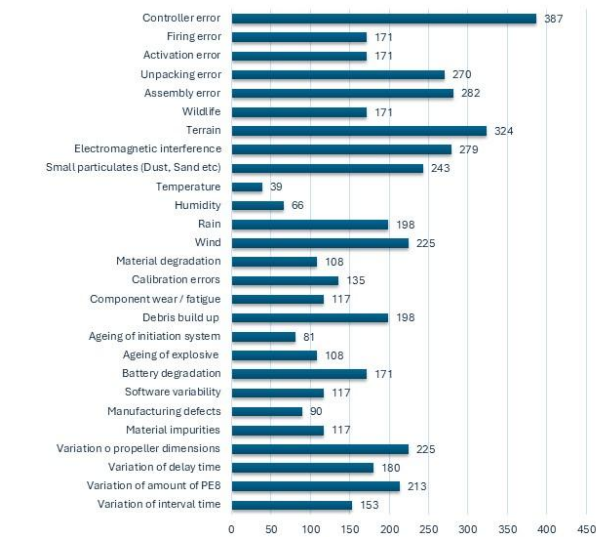
INTRODUCTION

OM

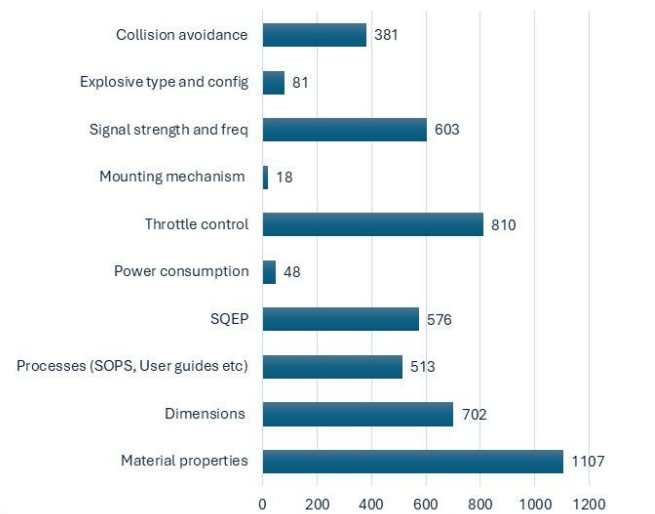
QFD2 Results - Feature Importances



Noise Factors



Control Factors



Technical Research and Design

Rebecca Dingwall

TECHNICAL RESEARCH AND DESIGN

RD

Additional analyses of available Commercial Of The Shelf (COTS) light-show drones was performed against some of the following criteria:

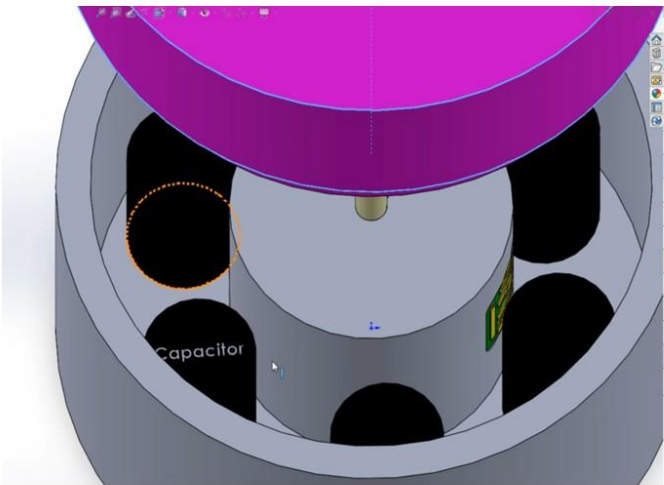
-  Collapsible unit
-  Simple to Assemble
-  Lifting capacity
-  Operator interface
-  GPS/IPS
-  Camera
-  Man portable
-  Has the ability to be used manually while also having some autonomy

These analyses were conducted to certify the level of conformity to:

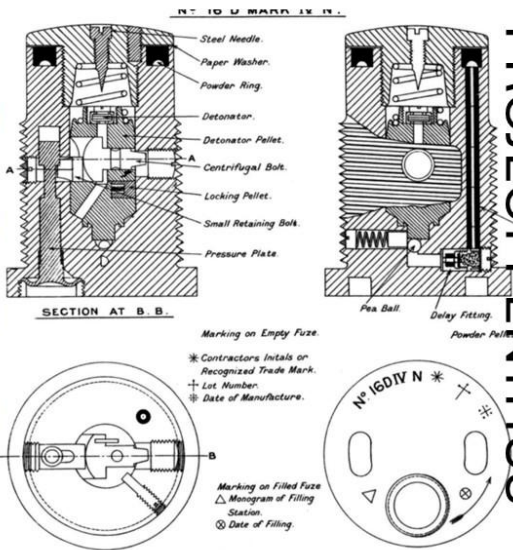
- ✓ The original requirement set
- ✓ Original functions means analysis as well as the
- ✓ Failure mode analysis conducted by the safety team.

RD

Subsystem function means:



Concept Design 1- containing features selected in blue.



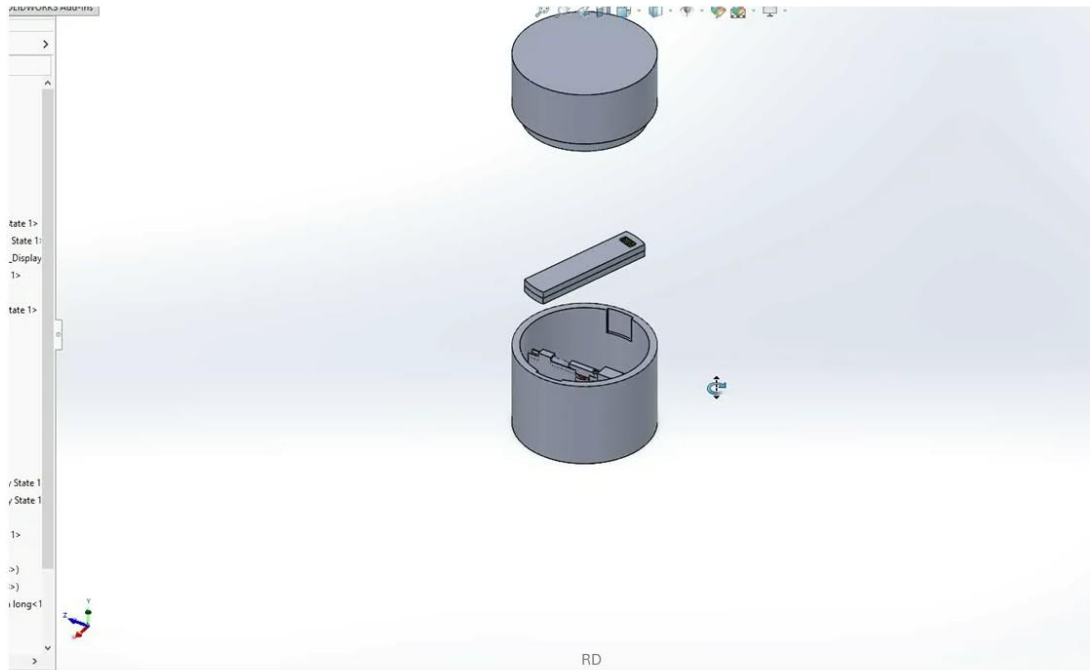
Concept Design 2- containing features selected in green.

PROJECT PENTHUS

Criteria used for the analysis of the design:

		£ Resource Efficiency	£ Operational costs	Ease of manufacture	Environmental impact (minimal)	Maintenance requirements	Flexibility of design (potential to increase charge size later if required)	Scalability (to be able to adapt to future needs)	Win per category	
D2	Vs D1									
Metron used to actuate the safe arming system	Discharge of a bank of capacitors	0	0	0	D2	D2	D2	D2	D2	
Mild steel	Plastic	D1	0	D1	D2	0	0	0	D1	
Case	Ball bearings	D2	0	D2	0	0	D2	0	D2	
0.5mm	5mm	0	0	0	D2	0	0	0	D2	
Lead azide	Xenon dioxide	D2	0	D2	D1	0	0	0	D2	
PETN	phlegmatized RDX	D2	0	D2	D2	0	D2	D2	D2	
(changed to from RDX/Wax) PE8	Comp B (RDX/TNT)	D2	0	D2	0	0	D2	0	D2	
Paint	Vinyl Wrap	D2	D2	D2	D2	D2	0	0	D2	
								Top Choice:	D2	0= The same or N/A
								LINK to Justification Doc...		

PROJECT PENTHUS

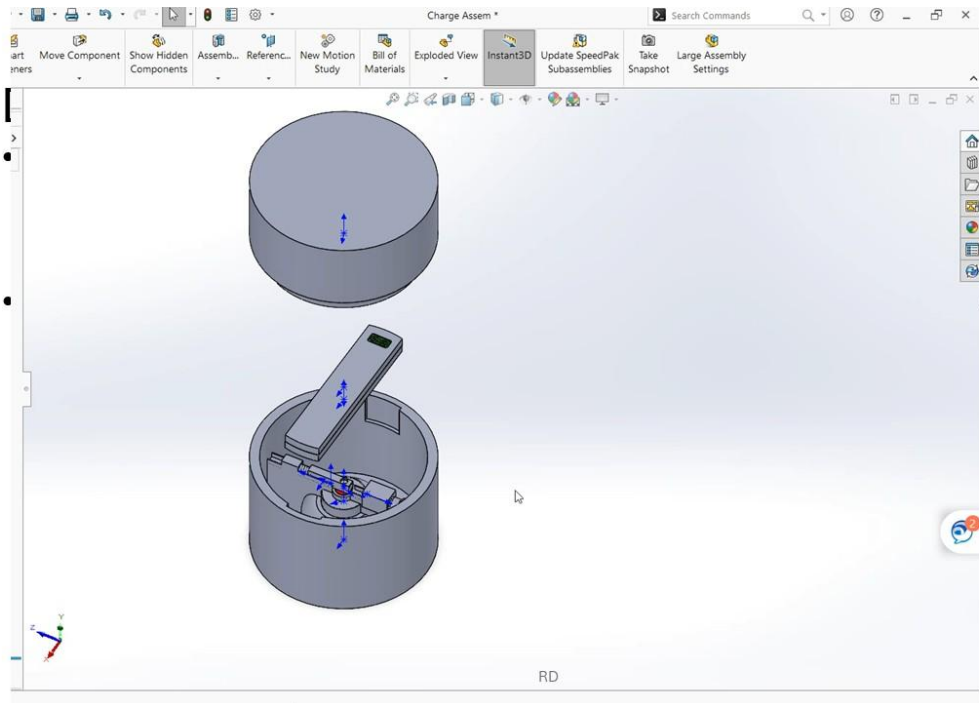


PROJECT PENTHUS

Critical Design Features

- Design of the Integration feature to the COTS system
- Safe arming mechanism design
- Dimensions of charge size
- Overall weight of munition
- 500g charge gives roughly the same amount of energy of a bare 416g TNT charge.
- NEQ reduced due to the stretch requirement to incapacitate room occupants over delivering a charge with effects incompatible with life.

PROJECT PENTHUS



Trial Proposals:

Computational and Mathematical Modeling:

- ✳ Blast radius estimations
- ✳ The fragment size, mass and spread
- ✳ Fragment velocities with fragment mass to calculate estimations of depth penetration and/or perforation into a variety of materials at set distances.

Full scale arena trial to validate models and document:

- ✳ The fragment size, mass and spread
- ✳ The penetration depth into strawboard frag packs
- ✳ HSV for fragment velocity
- ✳ 3-5 shots to collect data

Safety testing to assess and document:

- ✳ Attempt to initiate the device in 'safe' mode
- ✳ Cyclic heating
- ✳ Other safety testing

Collaborative Working & Key Communications :

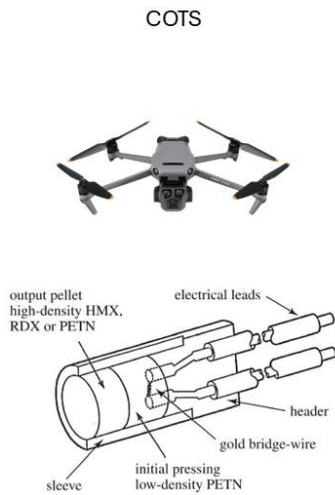
- Manufacturing Owen- Charge size and Dimensions
- Disposal JJ- NEQ, Trials data, projection hazard of fragments.
- Safety Team David & Harry – Discussion and in-depth explanation on points of interaction, justification and compatibility group etc.

RD

Manufacturing

Owen Miller

Manufacturing Requirements based on design



To Manufacture

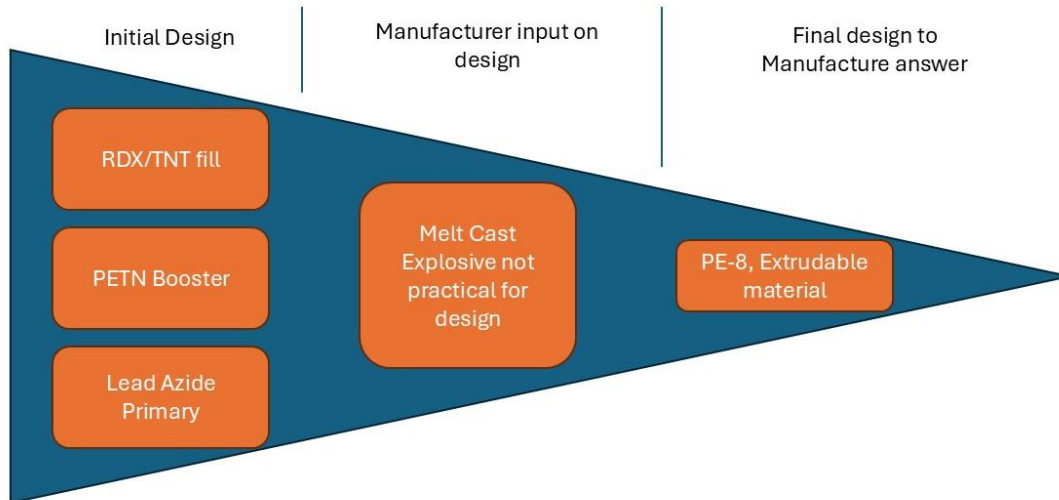


PROJECT PENTHUS

MANUFACTURING

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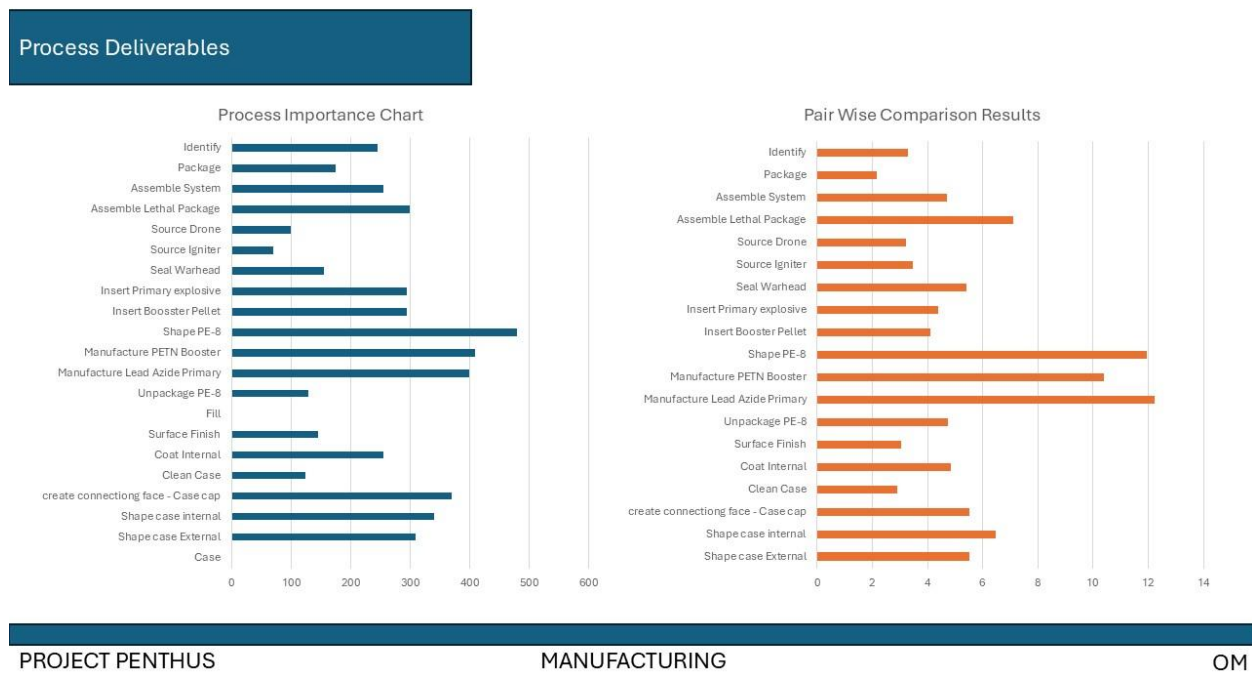
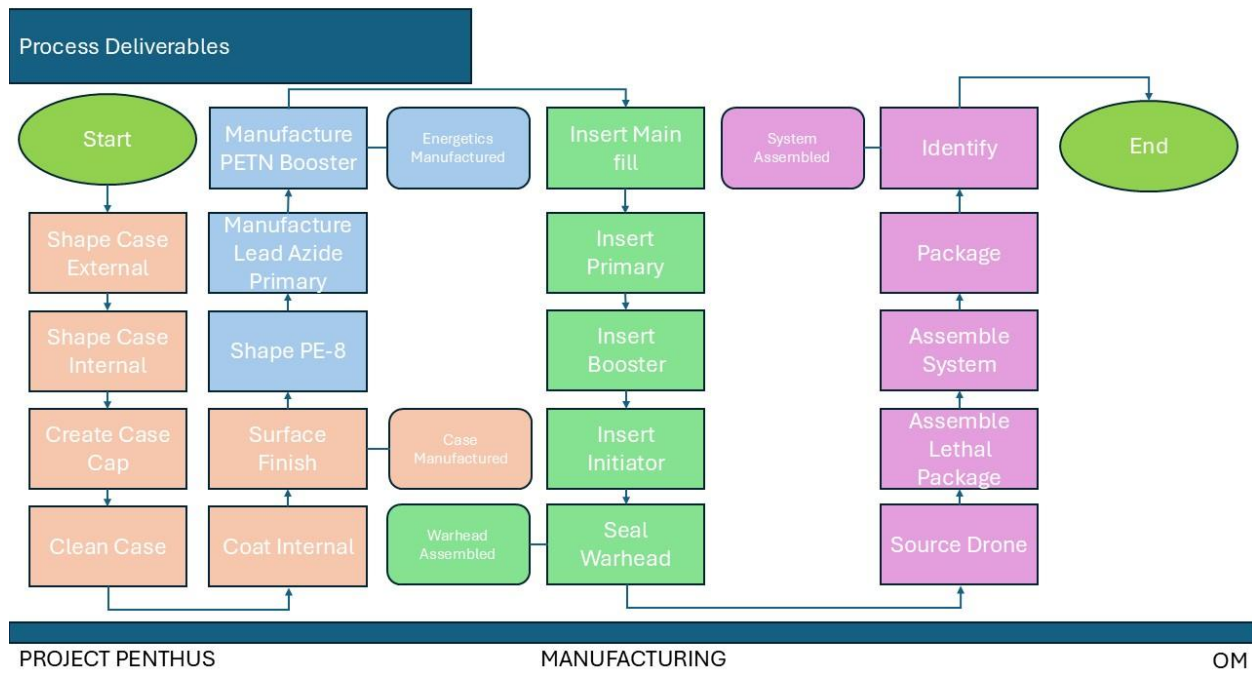
Design for manufacture

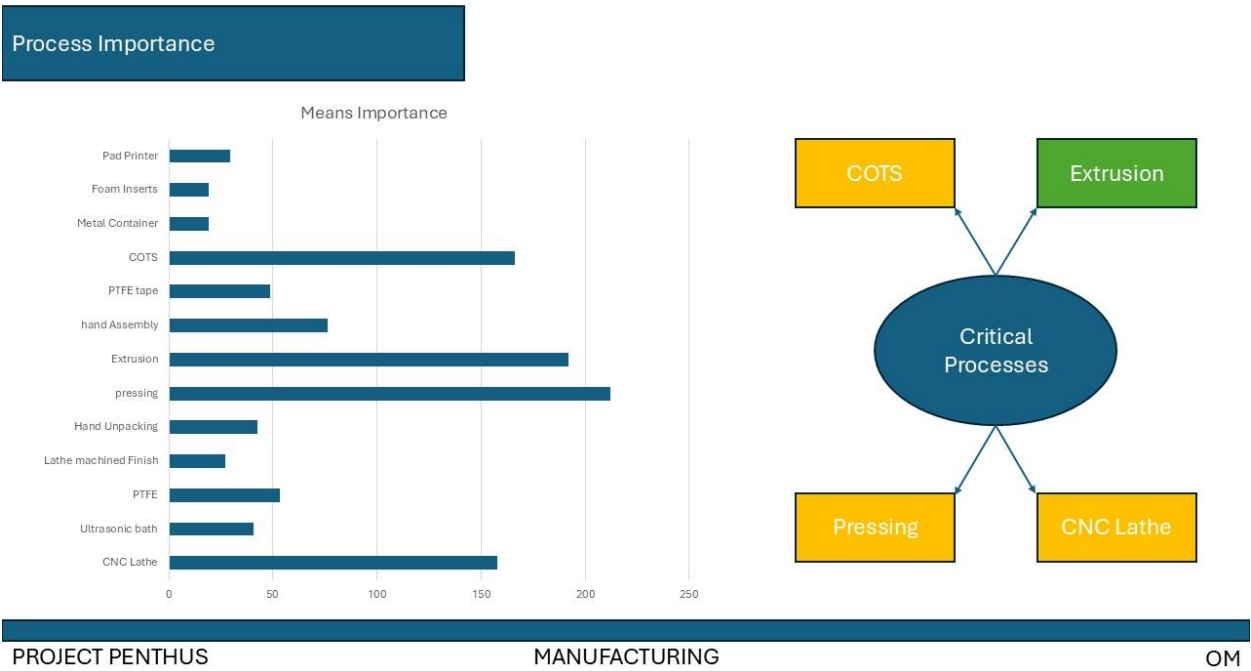
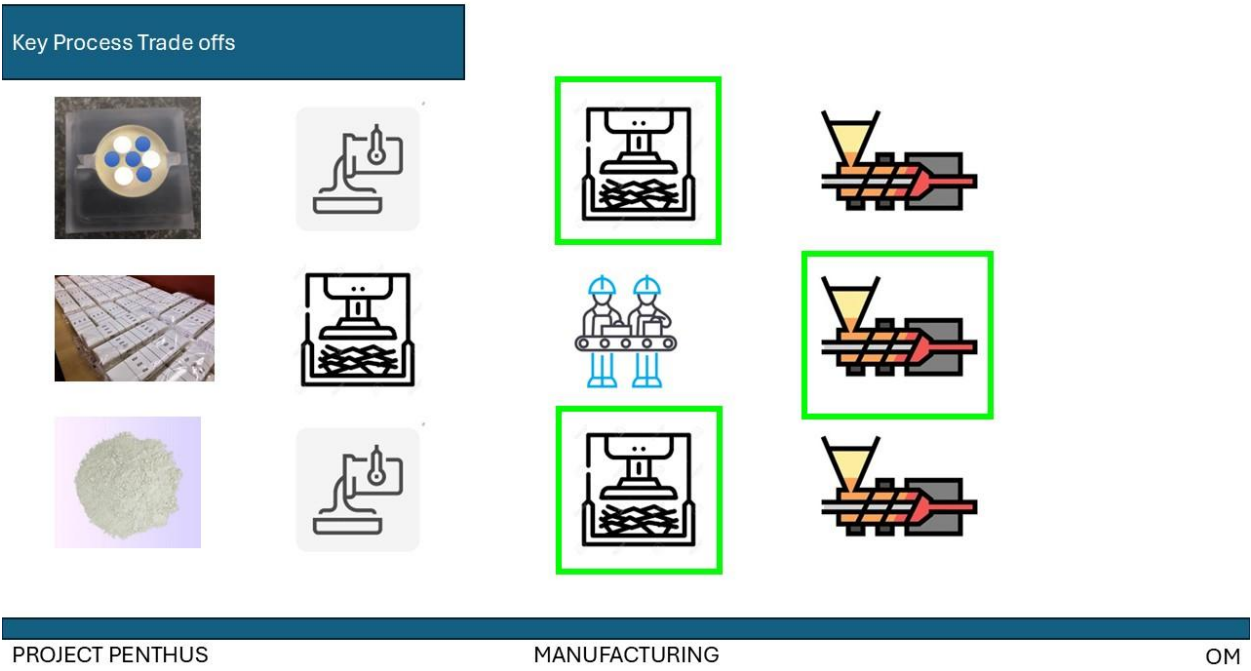


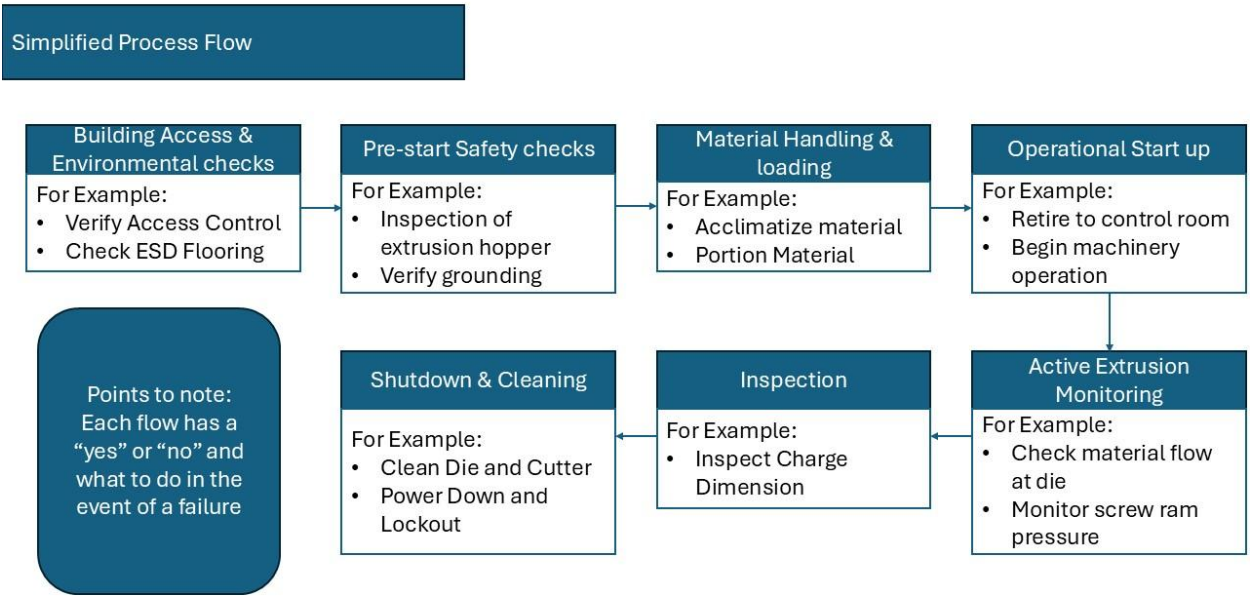
PROJECT PENTHUS

MANUFACTURING

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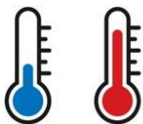




PFMEA/QFD 4 Outputs

- PFMEA analyses all 42 Process Steps
- 12 identified as High-Risk Failure Modes

Operation Number	Operation Description	Potential Failure Mode	Failure Mode Class	Potential Effects of Failure	S E V	Potential Causes	Prevention Controls	O C C	Detection Controls	D E T	RPN
11	Inspect for Extruder Screw Ram scoring, residue, or wear	Extruder Screw Ram Damaged	Product Quality	Material stuck in non finished surface Product outside of tolerance future material contamination	5	Machine Fatigue Insufficient Maintenance	Operator Training Standardise Maintenance Protocol Standardise Inspection	3	Visual inspection Maintenance Checks	3	45



PROJECT PENTHUS

MANUFACTURING

OM

Process Control Plan

Operation Number	Operation Description	Machine, Device, Jig, Tool	Characteristic to be controlled		Control Class	Control Method							Reaction Plan if Control Method fails
			Product Characteristic	Process Parameter		Element Evaluated / Measured	Specification / Tolerance	Evaluation / Measurement Technique	Sample		Record	Assurance of Control (incl. Procedure)	
10	Ensure Extrusion Hopper grounding cable is secure	Grounding Cable and clamp	N/A	Electrical Continuity	CTS	Clamp Connection and condition	No Damage	Visual Inspection	1	Pre-shift	Pre-Start Checklist	Continuity check	Maintenance to Replace cable/clamp; reverify before proceeding
11	Inspect for Extruder Screw Ram scoring, residue, or wear	Extruder Screw Ram	Mechanical Integrity	N/A	CTQ & CTS	Ram surface	No scoring/residue	Visual Inspection	1	Pre-shift	Maintenance Checklist	Inspection	Stop process and escalate for Maintenance inspection and repair



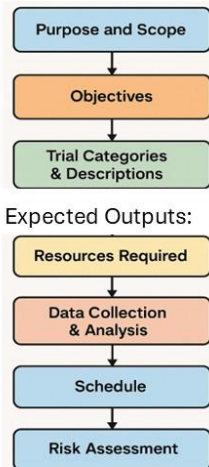
PROJECT PENTHUS

MANUFACTURING

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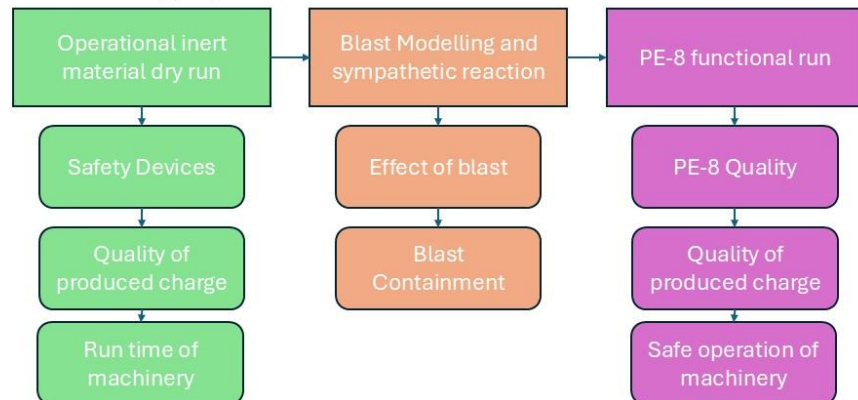
Manufacturing Testing

Supplied to testing Facility:



Expected Outputs:

Desired testing program flow:



PROJECT PENTHUS

MANUFACTURING

OM

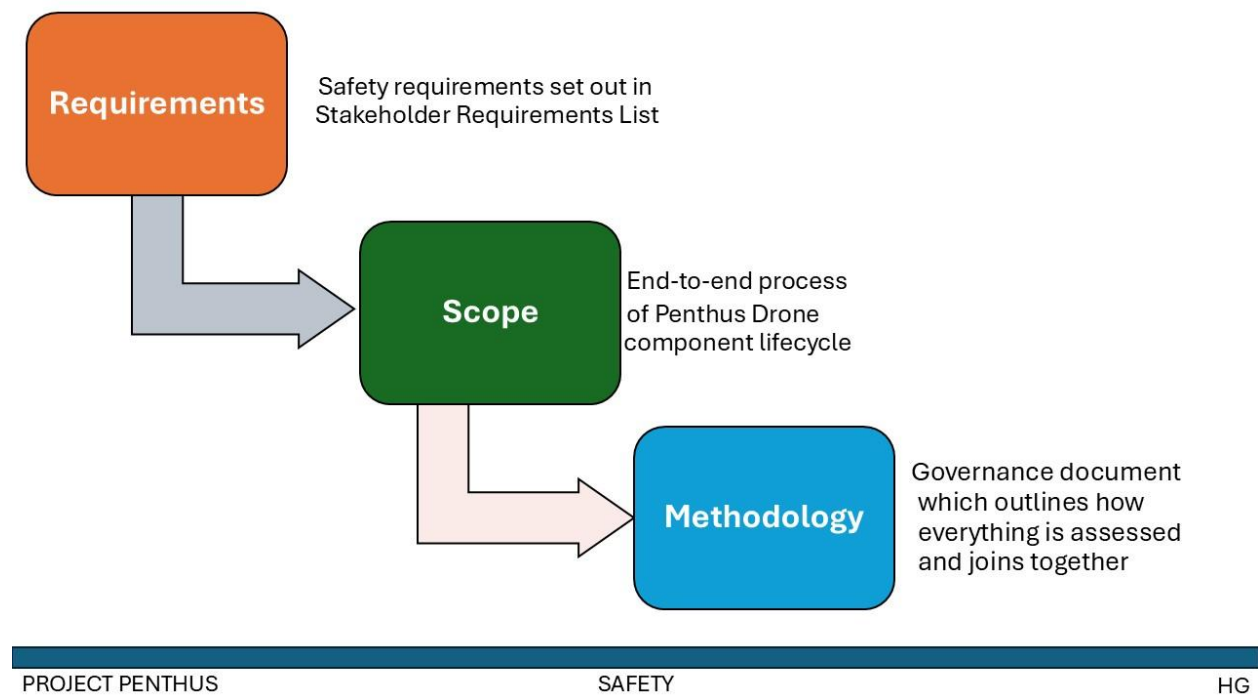
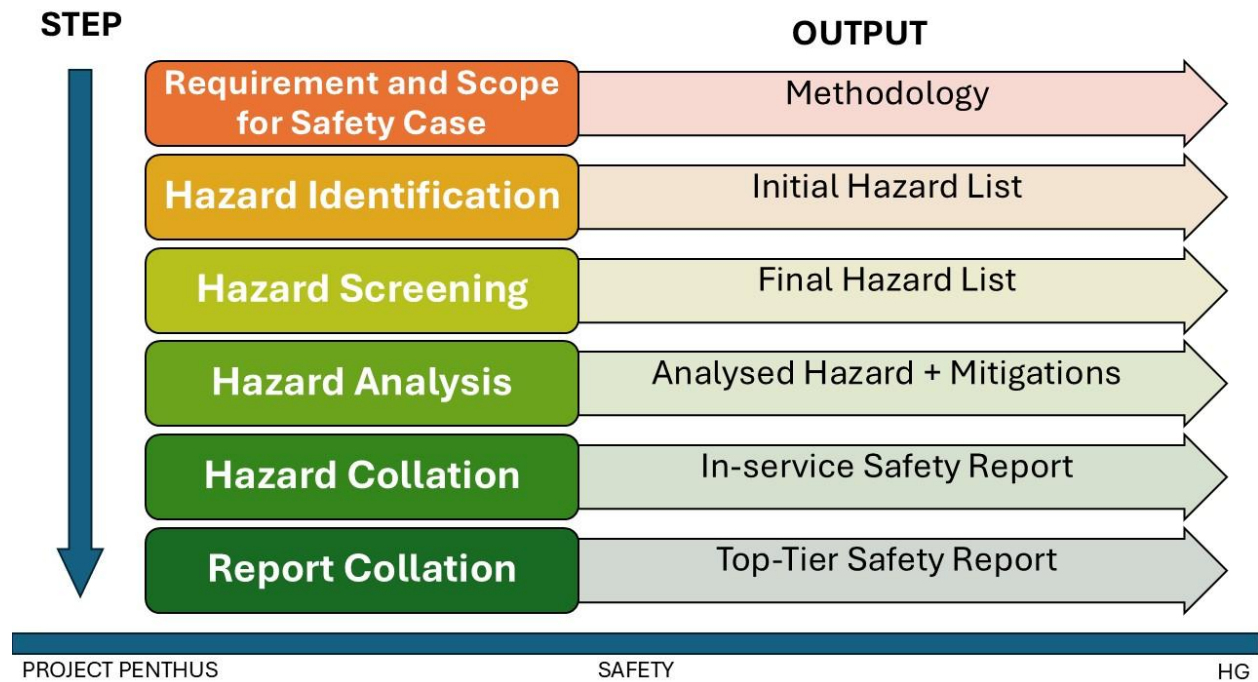
Safety

Harry Grinstead

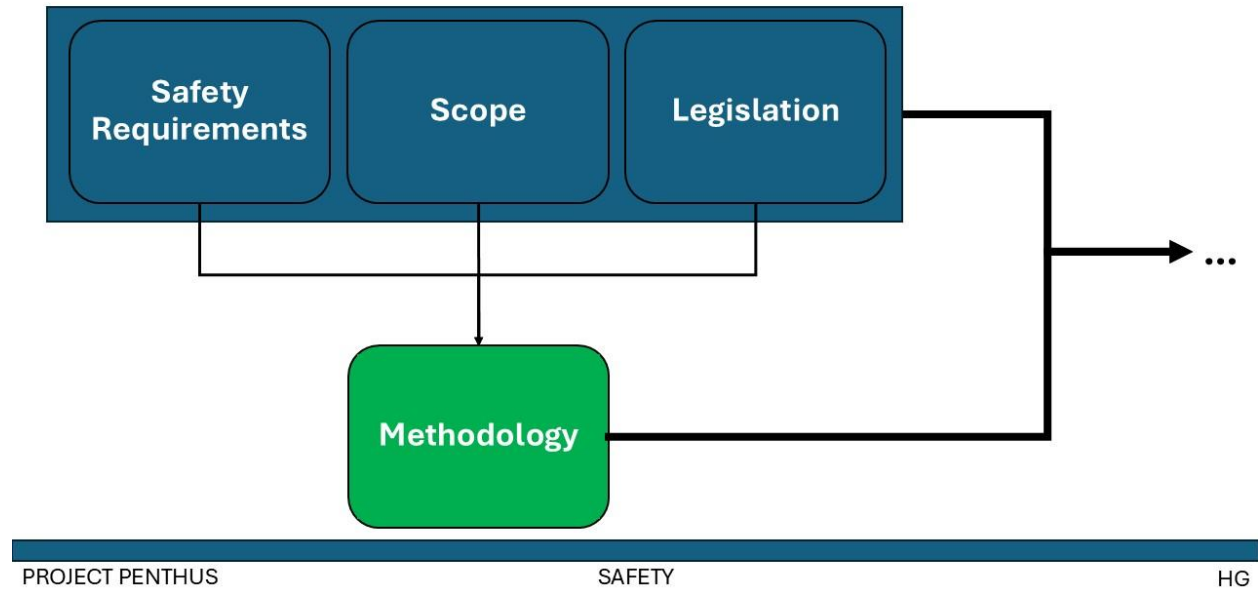
PROJECT PENTHUS	SAFETY	HG
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Understanding of the safety requirements for the area selected	Understanding of the legal safety deliverables	Identification of the key hazards in the selected area of operation	Critical analysis of the key hazards	Description of the mitigation required to be included in procedures	Development of the basis of safety
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PROJECT PENTHUS	SAFETY	HG
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What drives Safety?



Hazard Identification

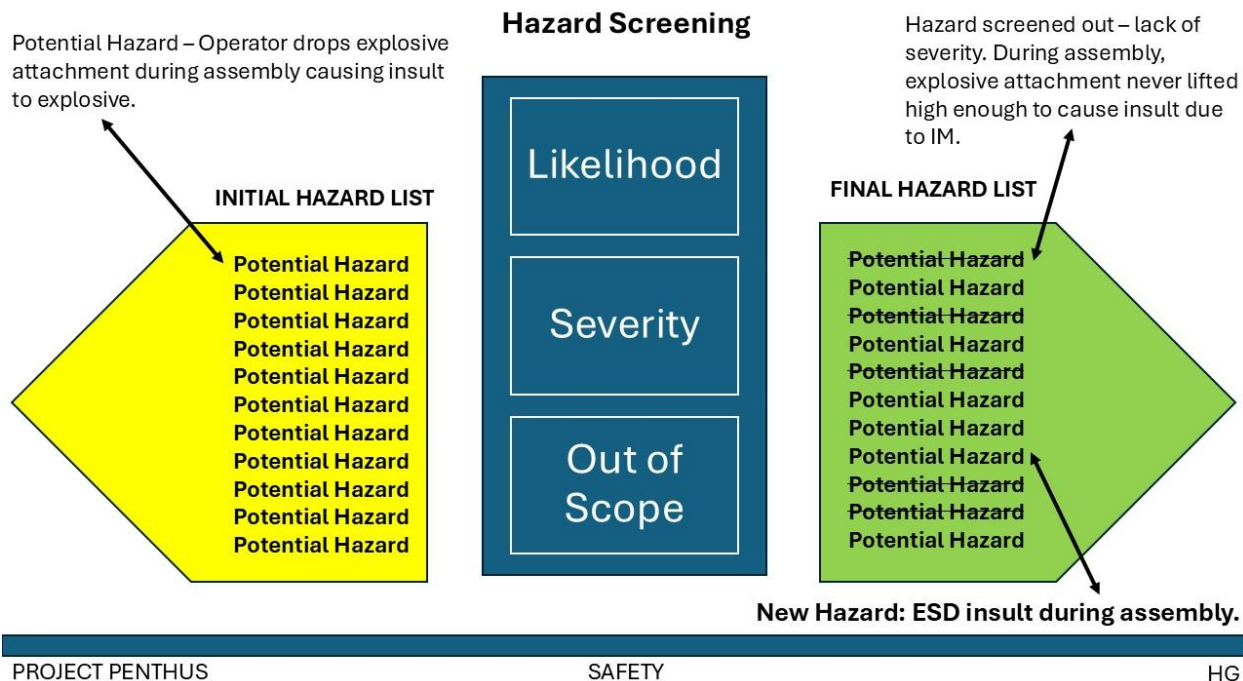
- An organised brainstorm of key stakeholders and SQEP Personnel to identify hazards within a specified activity.
- List of key words for each step of the process to prompt ideas for what could go wrong.
- For example:

Step – Assembly (In-Service)
Keyword – Drop

- Potential Hazard – Operator drops explosive attachment during assembly causing insult to explosive.

INITIAL HAZARD LIST

Potential Hazard
Potential Hazard
Potential Hazard
Potential Hazard
Potential Hazard
Potential Hazard
Potential Hazard
Potential Hazard
Potential Hazard
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Potential Hazard

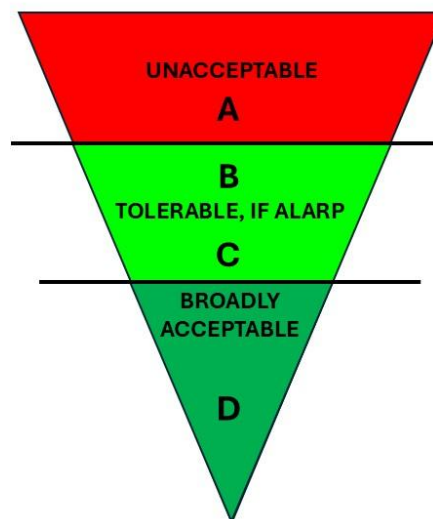


Pre mitigated ESD Example

Risk Classification

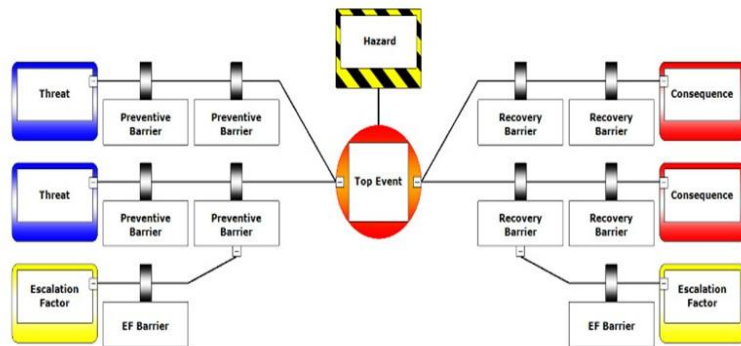
		SEVERITY			
		Catastrophic	Critical	Marginal	Negligible
Frequency of Occurrence	Frequent	A	A	A	B
	Probable	A	A	B	C
	Occasional	A	B	C	C
	Remote	B	C	C	D
	Improbable	C	C	D	D
	Incredible	C	D	D	D

Risk Class	Definition
A	Intolerable, and shall not be accepted. A formally delegated person may only accept this risk in extraordinary circumstances.
B	Undesirable, and shall only be accepted by the PTL, or equivalent, when further risk reduction is impracticable.
C	Tolerable with the endorsement of the Safety Committee if risk is demonstrated to be ALARP.
D	Broadly acceptable, but risk shall be monitored by the Safety Committee to ensure that it remains ALARP.



Qualitative Hazard Analysis

- Use “Claim Argument Evidence” Structure to create narrative around a potential hazard.
- Identify controls around the system and mitigations within the system.
- If you have enough controls/ mitigations identified, then you are deterministically compliant.



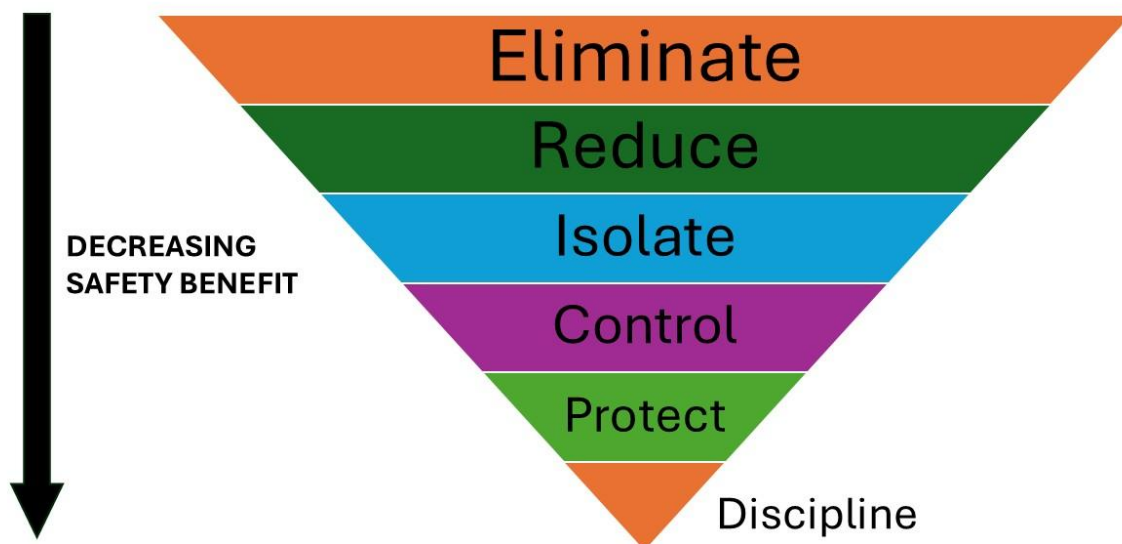
BOW-TIE DIAGRAM

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Hierarchy of Controls



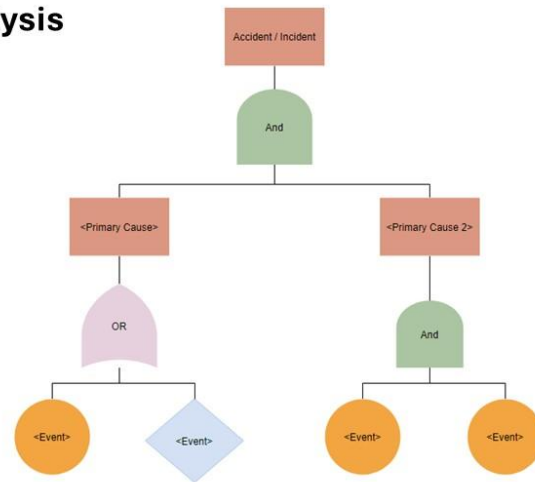
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Quantitative Hazard Analysis

- Numbers are put against the events and consider which events must occur and in what combinations for the incident to occur.
- Allows for a more realistic view of how a threat may progress as it considers the initiating event frequency.
- Provides an overall risk value which can be compared to a set acceptable risk value to determine the hazard is tolerable and ALARP.



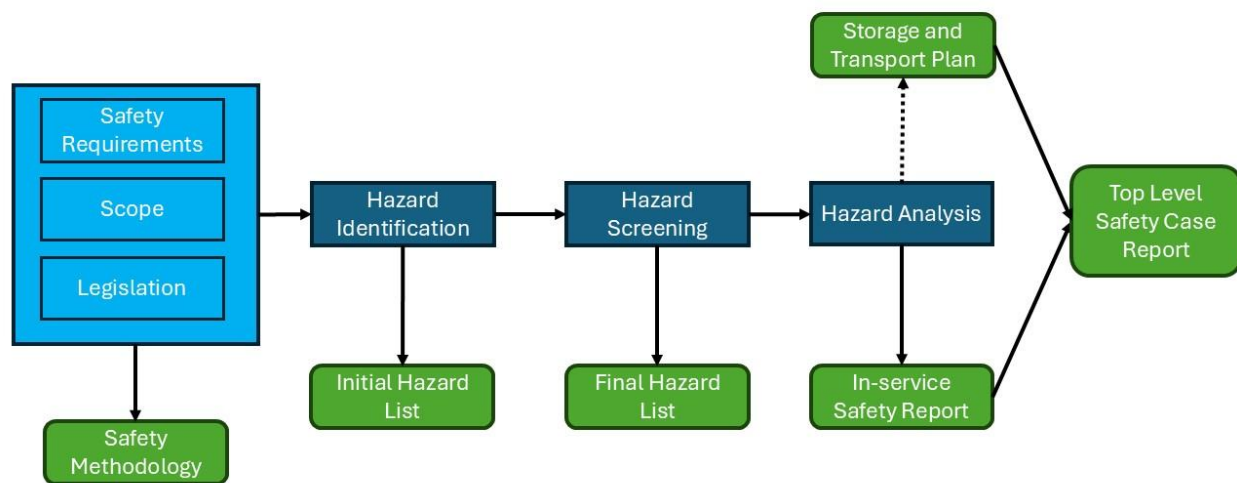
FAULT TREE DIAGRAM

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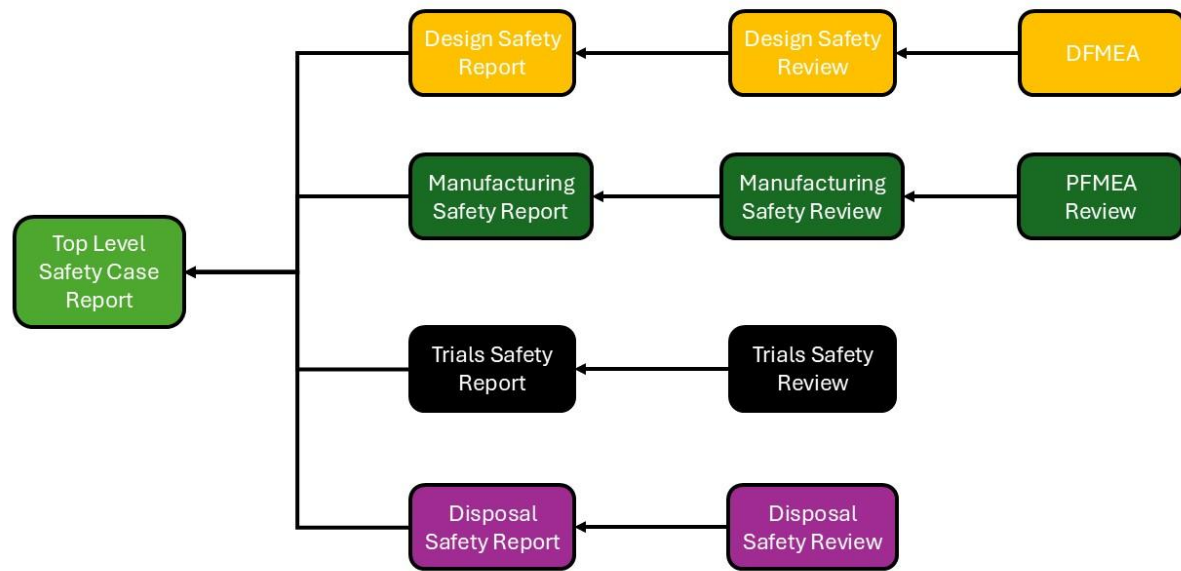
Safety Document Process Flow



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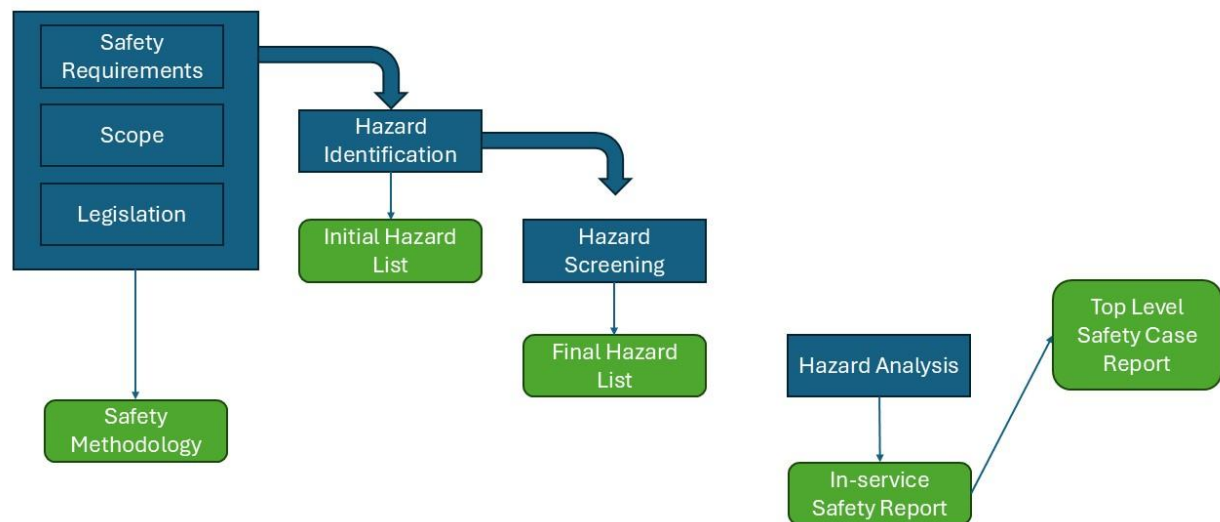
HG

Collaboration

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Legislation, Regulations and Frameworks

DSA02.OME

DSA03.OME

ER 2014

COMAH 2015

Def Stan 00-56

DSEAR 2002

Generic H&S Legislation

HASAWA 1974

MHASAW Regulations 1999

COSHH 2002

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Storage and Transport Safety

David Tolhurst

PROJECT PENTHUS

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Storage

These are the 5 main hazards identified for storing the explosive:

- Fire
- Moisture ingress
- Drop/Impact
- Electromagnetic Radiation
- Unauthorised access

Pre-mitigated risk class

	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med High	High	High
Likely	Low Med	Low Med	Medium	Med High	High
Probable	Low	Low Med	Medium	Med High	Med High
Unlikely	Low	Low Med	Low Med	Medium	Med High
Very Unlikely	Low	Low	Low Med	Medium	Medium
Risk Class	A	B	C	D	E

Storage

Mitigations to reduced overall risk from hazards present:

- Secure location
- Suitable container
- Environmentally controlled
- Free from contraband
- Fire fighting capabilities

Post-mitigated risk class

	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med High	High	High
Likely	Low Med	Low Med	Medium	Med High	High
Probable	Low	Low Med	Medium	Med High	Med High
Unlikely	Low	Low Med	Low Med	Medium	Med High
Very Unlikely	Low	Low	Low Med	Medium	Medium
Risk Class	A	B	C	D	E

Storage

Regulatory requirements:

- To comply with – DSA 03.OME Part 2 Chapter 10 “**Quantity distances and licensing criteria**”
- To comply with – DSA 03.OME Part 2 Chapter 12, Section 5.8 “**Controlled/Prohibited Articles and Contraband**”
- To comply with - DSA 03.OME Part 2 Chapter 13 “**Storage and Handling of Explosives**”
- To comply with - DSA 03.OME Part 2 Chapter 24 “**Hazards of Electromagnetic Radiation to Ordnance (HERO)**”



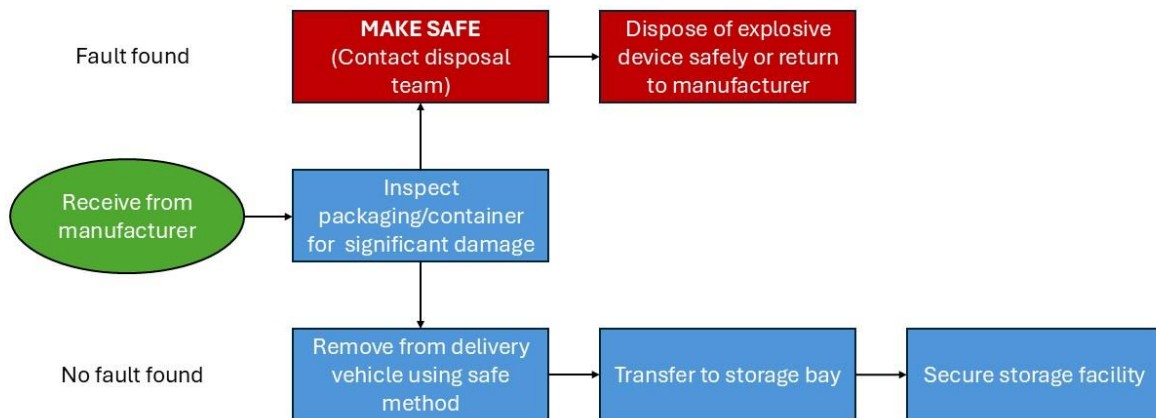
Storage

DSA 03.OME Part 2 Chapter 13

Compatibility Group D – “Secondary detonating explosive substance or black powder or article containing a secondary detonating explosive substance, in each case without means of initiation and without a propelling charge, **or article containing a primary explosive substance and containing two or more effective protective features**”

CG	A	B	C	D	E	F	G	H	J	K	L	S	N
A													
B			Note 1	Note 1	Note 1	Note 1	Note 1						
C		Note 1				Note 2	Note 3						Note 5
D		Note 1				Note 2	Note 3						Note 5
E		Note 1				Note 2	Note 3						Note 5
F		Note 1	Note 2	Note 2	Note 2		Note 2&3						
G		Note 1	Note 3	Note 3	Note 3	Note 2&3							
H													
J													
K													
L											Note 4		
S													
N			Note 5	Note 5	Note 5								

Storage process



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Transportation

These are the 3 main hazards identified for transporting the explosive:

- Fire
- Drop/Impact
- Vibration

Pre-mitigated risk class

	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med High	High	High
Likely	Low Med	Low Med	Medium	Med High	High
Probable	Low	Low Med	Medium	Med High	Med High
Unlikely	Low	Low Med	Low Med	Medium	Med High
Very Unlikely	Low	Low	Low Med	Medium	Medium
Risk Class	A	B	C	D	E

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Transportation

Mitigations to reduce overall risk from hazards present:

- Safe lifting/lowering procedures
- Environmental control
- Fire fighting capabilities
- Transport should avoid congested areas/times and plan a secondary route.

Post-mitigated risk class

	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med High	High	High
Likely	Low Med	Low Med	Medium	Med High	High
Probable	Low	Low Med	Medium	Med High	Med High
Unlikely	Low	Low Med	Low Med	Medium	Med High
Very Unlikely	Low	Low	Low Med	Medium	Medium
Risk Class	A	B	C	D	E

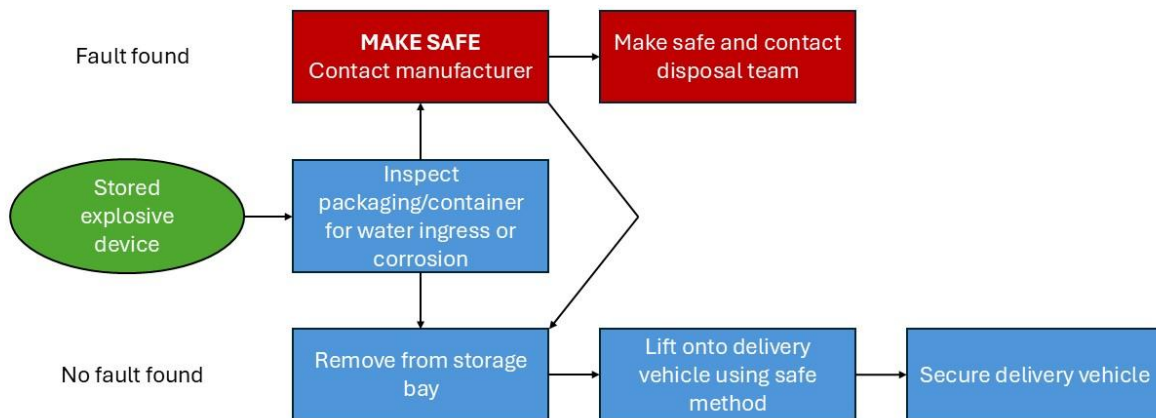
Transportation

Regulatory requirements:

- To comply with – Health and Safety Executive (HSE) **Explosive Regulations 2014**
- To comply with – **The Carriage of Dangerous Goods by Road (CDGR)**
- To comply with – **The Carriage of Dangerous Goods by Rail (CDG Rail)**
- To comply with – **The Carriage of Dangerous Goods by Air (CDGA)**



Transportation process



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SAFETY

DT

Breakdown and Disposal

John James

PROJECT PENTHUS

BREAKDOWN AND DISPOSAL

JJ

Disposal Requirements

Two separate sets of disposal requirements were necessary, as the nature of the components to be disposed of were disparate in nature. They could be reduced to two main categories:

Hazardous waste: primarily produced by the energetics but could also be contained within the delivery system.

Non-Hazardous Waste: primarily the delivery system.

Delivery System Disposal Requirements

- A requirement can be placed on the delivery system to have been built against the requirements laid out in, for example, ISO 14001: 2015 Environmental Management System. This will ensure that a structured approach to the disposal and waste management of its manufacture would have been applied.
- - Can be disposed of via conventional methods.

Energetics Disposal Requirements

- Can be separated from the delivery system and therefore be modular in nature.
- Can be disposed of via conventional methods within a defined disposal life.

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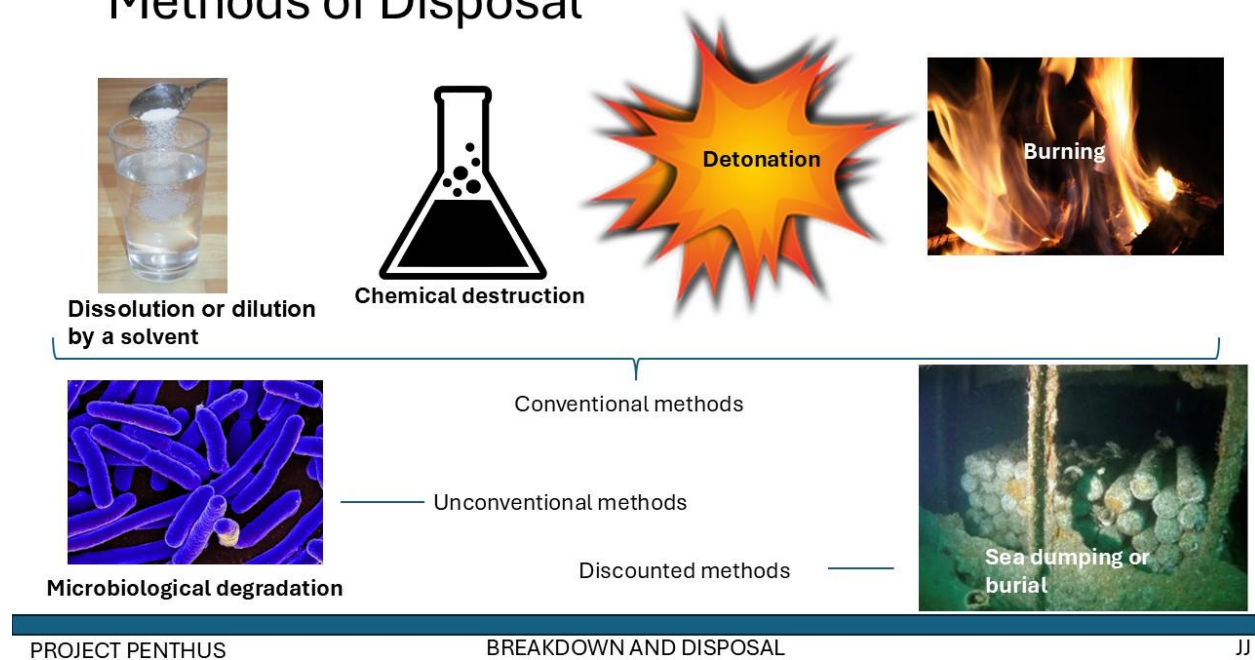
Delivery System Disposal Requirements

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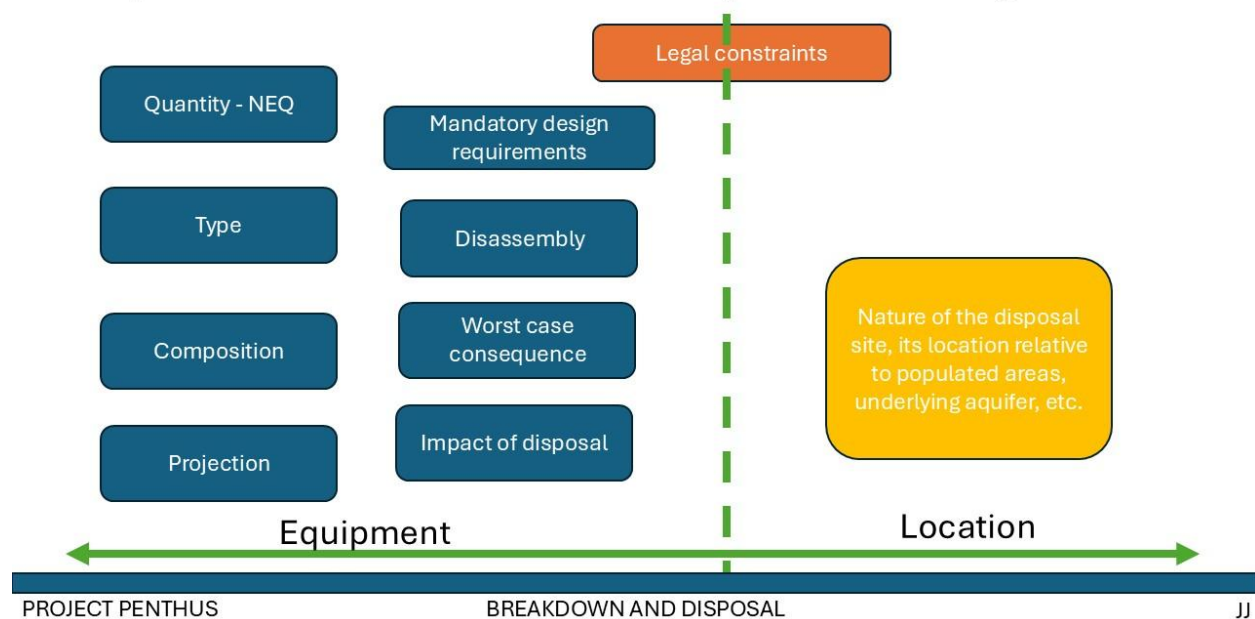
Energetics Disposal Requirements

- Can be separated from the delivery system and therefore be modular in nature.
- Can be disposed of via conventional methods within a defined disposal life.

Methods of Disposal



Aspects to Consider for the Disposal of Energetics



Hazard Analysis

- ‘An essential element of any disposal or destruction process involving explosives is hazard identification and risk analysis. Paragraph 431 of the ACOP to MSER states: - ‘
 - “A risk assessment is required to decide the most suitable method of disposal. The assessment needs to consider the nature of the explosive and its hazards, the disposal method and hazards created during the disposal process, and the type and position of the disposal site”

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BREAKDOWN AND DISPOSAL

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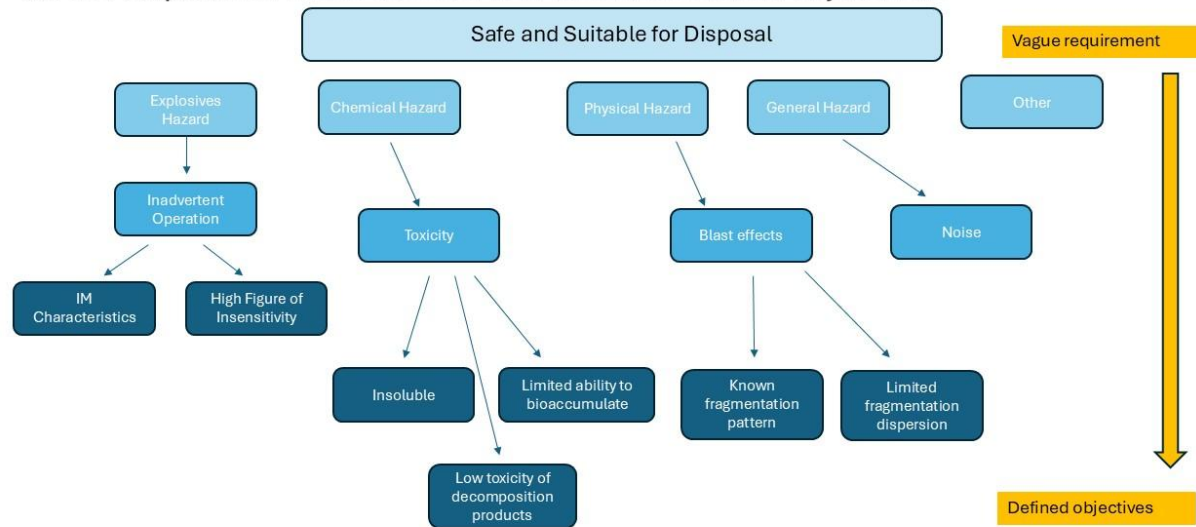


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BREAKDOWN AND DISPOSAL

JJ

The hazard identification process lends itself to an Objective Tree methodology, whereby, the top-level general requirement of 'Safe and Suitable for Disposal' can be developed into more defined low level achievable objectives.



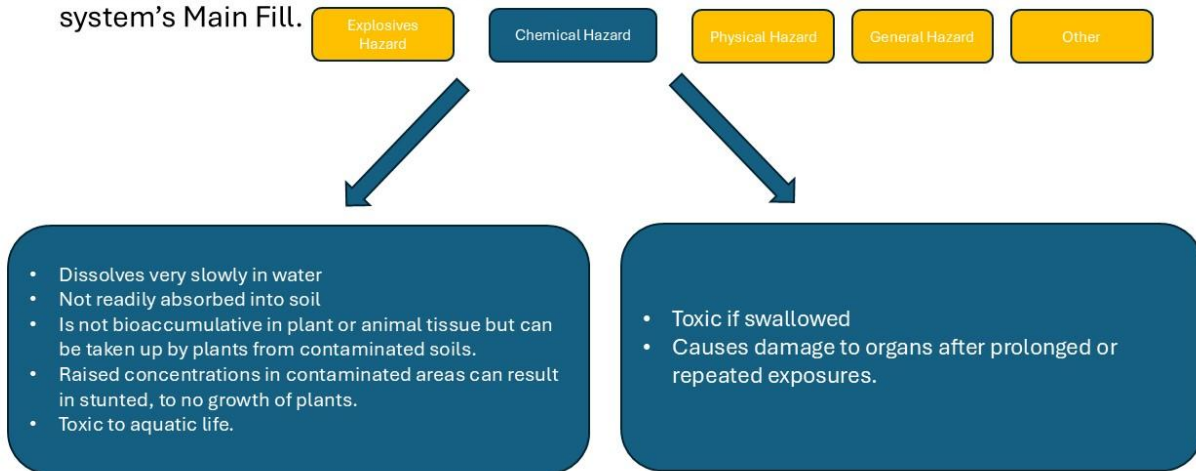
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BREAKDOWN AND DISPOSAL

JJ

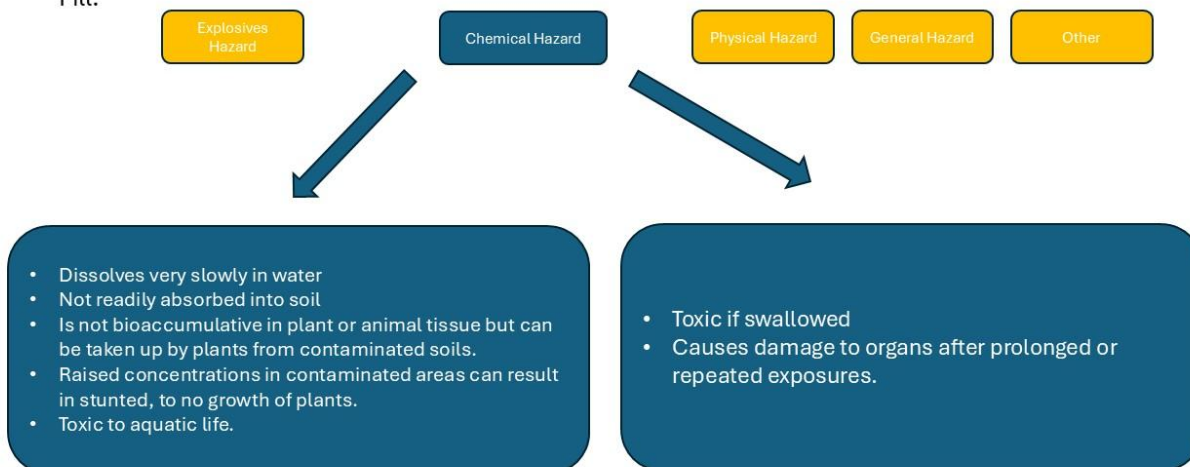
Disposal Hazard Analysis Synopsis

- Can be broken down into occupational and environmental hazard analysis. These can be used to inform the disposal requirements.
- Focusing on RDX, which constitutes 86.5% by weight of PE8, forming the weapon system's Main Fill.



Disposal Hazard Analysis Synopsis

- Can be broken down into occupational and environmental hazard analysis. These can be used to inform the disposal requirements.
- Focusing on RDX, which constitutes 86.5% by weight of PE8, forming the weapon system's Main Fill.

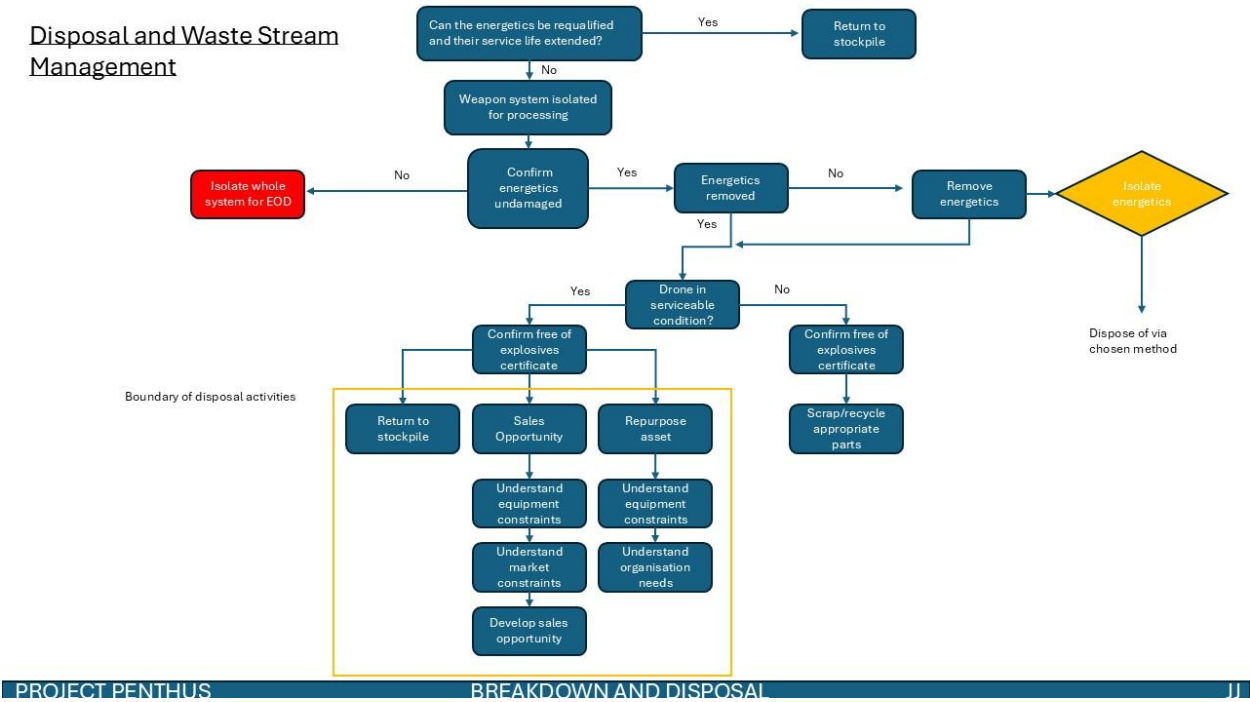


Chosen Method of Disposal for the Energetics



Principal reasons for choosing this method:

- The isolated nature of the disposal site makes it suitable.
- Other methods such as chemical destruction generate hazardous materials which would require further treatment.



Understanding of the breakdown and disposal Requirements for the area selected	Understanding the deliverables for design for disposal in test and production arenas	Identification of candidate disposal techniques for article and explosive disposal	Critical analysis of disposal design data	Feedback into the design process	Preparation of the waste stream management plan
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Any Questions?



PROJECT PENTHUS

Rebecca Dingwall, Harry Grinstead, John James, Owen Miller
and David Tolhurst

PROJECT PENTHUS

CONCLUSION

ALL

11. Appendix 3 – PFMEA

Operation Number	Operation Description	Potential Failure Mode	Failure Mode Class	Potential Effects of Failure	SEV	Potential Causes	Prevention Controls	OCC	Detection Controls	DET	RP N
1	Verify access control to extrusion bay	Building Locked	Process Safety	Operators cannot access building	3	Building Lock broken key lost Key Broken	regular Maintenance Spare Keys Spare Lock	1	Inspection	1	3
		Building Left Unlocked	Process Safety	Uncontrolled access to process	3	Operator not locking building Building lock Broken Key Lost	regular Maintenance Spare Keys Spare Lock	1	inspection Key Press	1	3
		personell in and out incorrectly logged	Process Safety	Uncontrolled access to process	3	Operator not signing in	Operator Training	3	inspection Key Press Log book	1	9
2	Check ESD flooring	Flooring Damaged	Process Safety	Not ESD safe	5	Dropped Objects Sharp Object Damage foreign object damage	PPE Cleaning sharp objects linked to work stations	2	PPE Inspection tool Shadow Boards	2	20
		Flooring Dirty	Process Safety	Not ESD safe	5	Incorrect Cleaning excessive dirt tracking Incorrect cleaning Products	PPE Cleaning Close Down Cleaning Procedure COSH cupboard stocked with correct cleaning products	4	Close Down procedure Inspection	1	20
3	Ensure blast shields and interlocks are engaged	Interlock Broken	Process Safety	no System Function explosive event causing excessive injury	2	incorrect maintenance incorrect operation	Standardised Maintenance Regime Operator Training	3	start up inspection regular maintenance check	3	18
		Blast shielding Not in place	Process Safety	no System Function explosive event causing excessive injury	5	incorrect maintenance incorrect operation	Standardised Maintenance Regime Operator Training	1	start up inspection regular maintenance check	1	5
		Blast shielding	Process Safety	no System Function explosive	3	incorrect maintenance incorrect operation	Standardised Maintenance	2	start up inspection regular maintenance check	1	6

		incorrectly fitted		event causing excessive injury			Regime Operator Training				
4	Confirm area is clean and free of foreign objects	Area Not Clean	Product Quality	Cross contamination of product	2	No cleaning completed Cleaning Insufficient	Operator Training	5	Visual Inspection	1	10
5	Energize control panels and PLCs	power not provided	Process Safety	Process not operable	1	Damaged Controls no power to building incorrect operation	Maintenance operator training	3	On/Off indicator	1	3
6	Verify fire suppression system status	Fire Suppresion system in suppression process	Process Safety	Building Flooded Process damaged personell injured	5	incorrect maintenance incorrect operation	Maintenance operator training	1	Maintenance inspection Regular Maintenance check	1	5
		Fire suppression system off	Process Safety	System non functional in emergency	5	incorrect maintenance incorrect operation	Maintenance operator training	3	Maintenance inspection Regular Maintenance check SOP Checks	2	30
		Fire suppression system leaking	Process Safety	Building Flooded Process damaged personell injured	3	incorrect maintenance incorrect operation	Maintenance operator training	3	Maintenance inspection Regular Maintenance check	2	18
7	Test interlocks and emergency stop	Interlocks and E-Stops Not Functional	Process Safety	Process non Functional process functional without guards in place E-Stop non functional in emergency situation	5	incorrect maintenance incorrect operation Interlocks Tampered with Electrical Fault Incorrect progScrew Ramming	Maintenance operator training inspection start up testing	4	Visual Inspection building start up test operation	1	20
8	Inspect Extrusion Drum for	Extrusion Drum contaminate d	Product Quality	Product Contaminatio n Equipment damage	3	Incorrect Cleaning incorrect Maintenance	Operator Training Standardised Maintenance Protocol	5	Visual inspection	2	30

	contaminants or residue										
9	Check Extrusion Drum for moisture	Extrusion Drum Moist	Product Quality	Product Contamination Equipment damage	3	Incorrect Cleaning incorrect Maintenance	Operator Training Standardised Maintenance Protocol	5	Visual inspection	2	30
10	Ensure Extrusion Drum grounding cable is secure	Grounding Cable Damaged	Process Safety	Product Ignition Electro Static Discharge Equipment Damage	5	Incorrect Cleaning Incorrect Operation incorrect Maintenance	Operator Training Standardised Maintenance Protocol	3	Visual inspection Maintenance Checks	3	45
		Grounding Cable not present	Process Safety	Product Ignition Electro Static Discharge Equipment Damage	5	Incorrect Cleaning Incorrect Operation incorrect Maintenance	Operator Training Standardised Maintenance Protocol	3	Visual inspection Maintenance Checks	1	15
11	Inspect for Extruder Screw Ram scoring, residue, or wear	Extruder Screw Ram Damaged	Product Quality	Material stuck in non finished surface Product outside of tolerance future material contamination	5	Machine Fatigue insufficient Maintenance	Operator Training Standardised Maintenance Protocol Standardised inspection	3	Visual inspection Maintenance Checks	3	45
12	Verify Screw Ram seal integrity	Screw Ram Seal Damaged	Product Quality	Material escaping press Excessive material to clean Screw Ram Jamming	3	Incorrect Cleaning Incorrect Operation incorrect Maintenance Machine Fatigue	Operator Training Standardised Maintenance Protocol Standardised inspection	2	Visual inspection Maintenance Checks	3	18
		Screw Ram Seal not present	Product Quality	Material escaping press Excessive material to clean Screw Ram Jamming	5	Incorrect Maintenance	Standardised Maintenance Protocol Standardised inspection	1	breakdown Inspection	5	25

13	Lubricate with approved dry film lubricant	not Lubricated	Process Safety	Excessive fatigue on Screw Ram Seal Scorning of Screw Ram Material Contamination	5	Incorrect Cleaning Incorrect Operation incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection	4	Visual inspection Maintenance Checks	1	20
		Too much Lubricant	Product Quality	Material Contamination	4	Incorrect Cleaning Incorrect Operation incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection	4	Visual inspection Maintenance Checks	3	48
14	Perform dry test spin	Screw Ram Does not Move	Process Safety	No Process Function Excessive pressure build up Machinery Damage	5	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	1	20
		Screw Ram moves too Quickly	Process Safety	Incorrect Process Function Excessive pressure loss Machinery Damage	4	Incorrect operation Incorrect Maintenance	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	2	32
		Screw Ram Moves too Slow	Process Safety	Incorrect Process Function Excessive pressure build up Machinery Damage	4	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	2	32
15	Check load sensors	Load Sensors Non functional	Process Safety	Incorrect Load recorded material Flow not logged	3	Incorrect Maintenance Incorrect Cleaning	Standardised Maintenance Protocol Standardised inspection operator training	3	Visual Inspection building start up test operation Maintenance Checks	2	18
		Load sensors reading incorrectly	Process Safety	Incorrect Load recorded material Flow not logged	3	Incorrect Maintenance Incorrect Cleaning	Standardised Maintenance Protocol Standardised inspection operator training	3	Visual Inspection building start up test operation Maintenance Checks	1	9

	16	Inspect die for cracks, wear, clogging	Die Damaged	Product Quality	Incorrect Product Dimension Material Lodged in Die Face	3	Machine Fatigue Incorrect Maintenance Incorrect cleaning Incorrect Operation Incorrect material used	Standardised Maintenance Protocol Standardised inspection operator training	3	Visual Inspection building start up test operation Maintenance Checks	1	9
	17	Clean die with soft brush and solvent	Die not clean	Product Quality	Contamination of output product	4	Incorrect Maintenance Incorrect Cleaning Incorrect Material used	Standardised Maintenance Protocol Standardised inspection operator training Standardised Closed Down and Start Up procedure	4	Visual Inspection building start up test operation Maintenance Checks	1	16
	18	Verify temperature control	Temperature control not reading correctly	Process Safety	Max Temperature Exceeded minimum Temperature not met	5	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	2	Visual Inspection building start up test operation Maintenance Checks	3	30
			Temperature control Non functional	Process Safety	Max Temperature Exceeded minimum Temperature not met	5	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	2	Visual Inspection building start up test operation Maintenance Checks	3	30
	19	Inspect cutter blade for damage	Cutter blade damaged	Product Quality	Incorrect Product Dimension Material Lodged in blade	3	Machine Fatigue Incorrect Maintenance Incorrect cleaning Incorrect Operation Incorrect material used	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	1	12
	20	Test blade movement with dry cycle	Cutter Doesn't function	Process Safety	Process Non functional	5	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	1	20
			Cutter Moves too quickly	Product Quality	Material Underdrawn	3	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	2	24

		cutter moves too slow	Product Quality	Material Overdrawn	3	Incorrect operation Incorrect Maintenance Machine Fatigue	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection building start up test operation Maintenance Checks	2	24
21	Clean surface of conveyor	surface not clean	Product Quality	Product Contaminated Excessive Belt Degrading	4	Incorrect Maintenance Incorrect cleaning Incorrect Operation Incorrect material used	Standardised Maintenance Protocol Standardised inspection operator training Standardised Closed Down and Start Up procedure	5	Visual Inspection building start up test operation Maintenance Checks	1	20
22	Inspect rollers	rollers damaged	Process Safety	Belt Non Functional	4	Incorrect Maintenance Incorrect cleaning Incorrect Operation Incorrect material used	Standardised Maintenance Protocol Standardised inspection operator training Standardised Closed Down and Start Up procedure	4	Visual Inspection building start up test operation Maintenance Checks	2	32
		Rollers not present	Process Safety	Belt Non Functional	4	Incorrect Maintenance Incorrect Operation	Standardised Maintenance Protocol Standardised inspection operator training	2	Visual Inspection building start up test operation Maintenance Checks	1	8
23	Test emergency stops	Emergency stop non functional	Process Safety	No instant shut down capability	5	Power Failure Incorrect Maintenance Incorrect Operation	Standardised Maintenance Protocol Standardised inspection operator training Electricity back up system	3	Visual Inspection building start up test operation Maintenance Checks	1	15
24	Move PE-8 into bay in approved quantity	Incorrect Energetic Supplied	Product Quality	Ignition of Energetic in process Contamination of process	5	Supplier Error incorrect marking operator Error Supply chain breakdown	Operator Training Supplier Audit	2	Visual inspection Material Transport container marking	1	10
		Incorrect Quantity transported	Process Safety	Ignition of Energetic in process Over spill of material Excessive Material remaining	5	Operator Error	Operator Training	4	Visual inspection Material Transport container marking Scale Weighing	1	20

		Not transported correctly	Process Safety	Ignition of Energetic Injury of operators product contamination	5	Operator Error	Operator Training	4	Visual inspection Material Transport container marking	1	20
25	Acclimate material to room temperature	Material Not acclimatised	Product Quality	Product out of specification damage to Process	3	Operator Error	Operator Training Building maintenance	4	Fixed Acclimatisation timer Surface thermometer	3	36
26	Portion feed into sealed hopper	Material Not portioned correctly	Process Safety	Material Overspill Damage of Machinery	5	Operator Error	Operator Training	3	Visual Inspection	1	15
27	Retire to Control room	personel left in Process building	Process Safety	Personel injured	4	personell not leaving control room poor communication	Operator Training Lone working prohibition	4	Building Clearance check	1	16
28	Start extrusion cycle	Extrusion Cycle does not start	Process Safety	Mateiral built up in hopper No Product	4	Operator Error Incorrect Maintenance Machine Fatigue Part Failure	Standardised Maintenance Protocol Standardised inspection operator training Electricity back up system	2	Visual Inspection Pressure Gauges on/off system light	1	8
29	Monitor Screw Ram pressure	Screw Ram pressure increases	Process Safety	Damage to Screw Ram Spill of material	3	Operator Error Incorrect Maintenance Machine Fatigue Part Failure	Standardised Maintenance Protocol Standardised inspection operator training Pressure monitoring System	4	Visual Inspection Pressure Gauges	1	12
		Screw Ram Pressure Decreases	Process Safety	Build up of material Hydraulic fluid Spill	3	Operator Error Incorrect Maintenance Machine Fatigue Part Failure	Standardised Maintenance Protocol Standardised inspection operator training Pressure monitoring System	4	Visual Inspection Pressure Gauges	1	12

		Screw Ram has no pressure	Process Safety	No process function	4	Operator Error Incorrect Maintenance Machine Fatigue Part Failure	Standardised Maintenance Protocol Standardised inspection operator training Pressure monitoring System	2	Visual Inspection Pressure Gauges	1	8
30	Check material flow at die face	No material flow	Process Safety	Material Build Up No Material in Process	3	Operator Error Incorrect Maintenance Machine Fatigue Incorrect Material used	Standardised Maintenance Protocol Standardised inspection operator training Pressure monitoring System	3	Visual Inspection Pressure Gauges	1	9
		Excessive material flow	Product Quality	Material Build Up Product Splaying	3	Operator Error Incorrect Maintenance Machine Fatigue Incorrect Material used	Standardised Maintenance Protocol Standardised inspection operator training Pressure monitoring System	3	Visual Inspection	2	18
		Low Material Flow	Product Quality	Material out of spec Material build up	3	Operator Error Incorrect Maintenance Machine Fatigue Incorrect Material used	Standardised Maintenance Protocol Standardised inspection operator training Pressure monitoring System	3	Visual Inspection Pressure Gauges	1	9
31	Check uniformity of extrudate	Extrudate splaying	Product Quality	Material out of Spec	2	Operator Error Incorrect Maintenance Machine Fatigue Incorrect Material used Excessive material in process	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual Inspection	2	16

			Extrudate not filling die	Product Quality	Material out of Spec	2	Operator Error Incorrect Maintenance Machine Fatigue Incorrect Material used Insufficient material in process	Standardised Maintenance Protocol Standardised inspection operator training	2	Visual Inspection	2	8
			no extrudate	Process Safety	Material out of Spec	2	Operator Error Incorrect Maintenance Machine Fatigue Incorrect Material used Insufficient material in process	Standardised Maintenance Protocol Standardised inspection operator training	3	Visual Inspection	2	12
	32	Inspect for voids or discoloration	Voids present	Product Quality	Material out of Spec	4	Operator Error Incorrect Maintenance Incorrect Material used Insufficient material in process	Standardised Maintenance Protocol Standardised inspection operator training Material Supplier Audit	3	X-ray Visual Inspection	2	24
			Discoloration present	Product Quality	Material out of Spec Contaminated material	4	Incorrect Cleaning Incorrect Material used	Standardised Maintenance Protocol Standardised inspection operator training Material Supplier Audit Standardised Cleaning Process	3	Visual inspection	2	24
	33	Run out residual PE-8	Residual PE-8 not completely removed	Process Safety	Contamination of future batches ignition of material	4	Operator error	Operator Training Standardised Cleaning Process	4	Visual inspection Regular Maintenance Checks	2	32
	34	Reset Interlocks	Interlocks not reset	Process Safety	Process left in unsafe manner Injury to operator	5	operator error Incorrect Maintenance	Standardised Maintenance Protocol Standardised inspection operator training	4	Visual inspection Regular Maintenance Checks	1	20
			interlocks partially reset	Process Safety	Process left in unsafe manner Injury to operator	5	operator error Incorrect Maintenance	Standardised Maintenance Protocol Standardised	4	Visual inspection Regular Maintenance Checks	1	20

							inspection operator training				
35	Clean storage drum (wipe)	Cleaning insufficient	Product Quality	Process left in unsafe state Damage to process equipment Contaminatio n of future product	3	operator error Incorrect Maintenance Insufficient cleaning	Standardised inspection operator training Standardised Cleaning Process	2	Visual inspection Regular Maintenance Checks	1	6
36	clean Screw Ram with non-metallic scraper	Screw Ram Not Clean	Product Quality	Process left in unsafe state Damage to process equipment Contaminatio n of future product	3	operator error Incorrect Maintenance Insufficient cleaning	Standardised inspection operator training Standardised Cleaning Process	2	Visual inspection Regular Maintenance Checks	1	6
37	Clean Die	Die not clean	Product Quality	Process left in unsafe state Damage to process equipment Contaminatio n of future product	3	operator error Incorrect Maintenance Insufficient cleaning	Standardised inspection operator training Standardised Cleaning Process	3	Visual inspection Regular Maintenance Checks	1	9
38	Clean Cutter	Cutter not clean	Product Quality	Process left in unsafe state Damage to process equipment Contaminatio n of future product	3	operator error Incorrect Maintenance Insufficient cleaning	Standardised inspection operator training Standardised Cleaning Process	2	Visual inspection Regular Maintenance Checks	1	6
39	Wipe conveyor with anti-	Conveyor not clean	Product Quality	Process left in unsafe state Damage to process	3	operator error Incorrect Maintenance Insufficient cleaning	Standardised inspection operator training Standardised Cleaning Process	2	Visual inspection Regular Maintenance Checks	1	6

	static cleaner			equipment Contamination of future product							
40	Complete cleaning and inspection log	Log not filled in	Process Safety	Incorrect process control Limited Accountability batching Void	2	Operator Error Log not available	Operator Training supervisor inspection	4	Supervisory spot check	3	24
		Log filled in incorrectly	Process Safety	Incorrect process control Limited Accountability batching Void	2	Operator Error Log not available	Operator Training supervisor inspection	4	Supervisory spot check	4	32
41	Power down PLCs and lockout extruder	PLC not powered down	Process Safety	Process left in unsafe manner	4	Electrical Failure operator Error	Electrical Backup operator Training Standardised Maintenance	2		1	8
42	lockout extruder	Extruder not locked out	Process Safety	Process left in unsafe manner Injury to operator	5	Electrical Failure operator Error	operator Training Standardised Maintenance	2	inspection Key Press Log book	1	10

1. Appendix 4 – PCP

Operation Number	Operation Description	Machine, Device, Jig, Tool	Characteristic to be controlled		Control Class	Control Method							Reaction Plan if Control Method fails
			Product Characteristic	Process Parameter		Element Evaluated / Measured	Specification / Tolerance	Evaluation / Measurement Technique	Sample		Record	Assurance of Control (Incl. Procedure)	
									Size	Frequency			
PE-8 Extrusion													
1	Verify access control to extrusion bay	Key press and door locks	Controlled access	Physical key control	CT S	Key log and physical key access	Only authorised key holders	Visual + logbook check	1	Daily start-up	Access Log	Key control check	Report breach; restrict area access
2	Check ESD flooring	ESD flooring	Static dissipation	Surface resistance	CT S	Floor resistance	<10^9 ohms	ESD resistance meter	1	Weekly	ESD Log	Surface resistance check	Repair/re place flooring
3	Ensure blast shields and interlocks are engaged	Interlock switch, shield	Operator protection	Circuit status	CT S	Shield and switch function	Active / engaged	Visual + system check	1	Per shift	Safety Log	Inspection	Stop work; report issue
4	Confirm area is clean and free of foreign objects	Work area	Cleanliness	Foreign object detection	CT Q & CT S	Work area cleanliness	No foreign objects	Visual inspection	1	Pre-shift	Housekeeping Log	Inspection	Clean and recheck
5	Energize control panels and PLCs	PLC, Control Panel	System readiness	Power on state	CT S	System indicators	No faults; powered on	Visual check + self-test	1	Start-up	System Log	Startup check	Notify maintenance

6	Verify fire suppression system status	Fire Suppression Panel, Suppression lines	N/A	System Armed & Functional	CT S	Panel Status Light, Visual Line Integrity	Active + No Leaks	Visual Inspection	1	Daily Start-Up	Pre-Start Checklist	System check	Halt Operations; notify safety lead
7	Test interlocks and emergency stop	Interlock switch, shield	Operator protection	Circuit status	CT S	Shield and switch function	Active / engaged	Visual + system check	1	Per shift	Safety Log	Inspection	Stop work; report issue
8	Inspect Extrusion Hopper for contaminants or residue	Extrusion Drum	Cleanliness	N/A	CT Q & CT S	Inner Drum Surface	No Visible residue	Visual Inspection	1	pre-shift	Cleaning log	inspection	Clean drum again; report repeated build up
9	Check Extrusion Hopper for moisture	Extrusion Drum	Dryness	N/A	CT Q & CT S	Inner Drum Surface	No Moisture Present	Lint-free Wipe test	1	pre-shift	Cleaning log	inspection	Dry drum; check temperature and humidity in building is correct
10	Ensure Extrusion Hopper grounding cable is secure	Grounding Cable and clamp	N/A	Electrical Continuity	CT S	Clamp Connection and condition	No Damage	Visual Inspection	1	Pre-shift	Pre-Start Checklist	Continuity check	Replace cable/clamp; reverify before proceeding
11	Inspect for Extruder Screw Ram scoring, residue, or wear	Extruder Screw Ram	Mechanical Integrity	N/A	CT Q & CT S	Ram surface	No scoring/residue	Visual Inspection	1	Pre-shift	Maintenance Checklist	Inspection	Replace or escalate for review
12	Verify Screw Ram seal integrity	Ram seal housing	Seal condition	Compression fit	CT Q & CT S	Seal contact area	No leaks or looseness	Visual inspection	1	Weekly	Maintenance Log	Inspection	Replace seal; delay operations

13	Lubricate with approved dry film lubricant	Lubricant Dispenser	N/A	Application of lubricant	CT S	Ram lubrication status	Even coating, no excess	Visual + touch test	1	Pre-shift	Lubrication Log	Lubrication	Clean and reapply approved lubricant
14	Perform dry test spin	Extruder Assembly	N/A	Rotational Function	CT S	Rotation noise/speed	Smooth operation	Manual test spin	1	Pre-shift	Test Log	Dry test	Inspect drive and bearings
15	Check load sensors	Load cell	Sensor accuracy	Calibration output	CT S	Sensor readout	Within calibrated range	Digital display reading	1	Monthly	Calibration Record	Sensor check	Recalibrate or replace
16	Inspect die for cracks, wear, clogging	Extruder Die	Structural integrity	Damage or obstruction	CT Q & CT S	Die face and openings	No visible cracks or clog	Visual + magnifier	1	Pre-shift	Inspection Log	Inspection	Replace die if damaged
17	Clean die with soft brush and solvent	Soft brush + approved solvent	Cleanliness	Surface residue	CT Q	Die face	Residue-free	Manual clean + wipe test	1	Per use	Cleaning Log	Cleaning	Repeat cleaning
18	Verify temperature control	Heater System + Thermocouple	N/A	Temp within safe range	CT Q & CT S	Temp at die head	60–70°C	Thermocouple sensor readout	1	Hourly during op	Batch Record	Temperature monitoring	Stop process; check heating element
19	Inspect cutter blade for damage	Cutter Blade	Blade integrity	Edge condition	CT Q	Blade edge	No chips or bends	Visual inspection	1	Pre-shift	Maintenance Log	Inspection	Replace blade
22	Inspect rollers	Feed Rollers	Surface integrity	Roller wear/residue	CT S	Roller surface	No cracks/residue/wear	Visual inspection	2	Pre-shift	Maintenance Log	Inspection	Replace or clean rollers
21	Clean surface of conveyor	Conveyor Surface	Cleanliness	Debris on belt	CT Q & CT S	Surface of conveyor	No residue	Wipe and visual	1	Pre-shift	Cleaning Log	Cleaning	Clean again; escalate if persistent

22	Inspect rollers	Conveyor rollers	Wear and function	Roller spin and surface	CT S	Roller surface	No cracks/wear	Visual and manual spin	2	Weekly	Maintenance Log	Inspection	Replace rollers
23	Test emergency stops	E-stop Buttons	Emergency readiness	Circuit cut	CT S	E-stop function	Immediate system halt	Press test	1	Weekly	Safety Log	Functional test	Repair before use
24	Move PE-8 into bay in approved quantity	Handling tray	Material quantity	Batch size	CT S	Weighed quantity	Per SOP allowance	Scale check	1	Per batch	Batch Record	Weighing	Adjust to approved quantity
25	Acclimate material to room temperature	Material Staging Tray	Temperature compliance	Material Temp	CT Q & CT S	PE-8 surface temp	20–25°C	Contact thermometer	3	Per batch	Batch Prep Log	Temperature check	Delay loading until in range
26	Portion feed into sealed hopper	Sealed Hopper	Loading accuracy	Feed quantity	CT Q & CT S	Visual portioning	Even distribution	Scoop + visual	1	Per batch	Batch Prep Log	Loading	Report on material
27	Retire to Control room	Control Room	Operator safety	Distance from bay	CT S	Operator location	Outside bay	Visual confirmation	1	Per batch	Operation Log	Personnel check	Delay until all clear
28	Start extrusion cycle	Extruder Controls	Start sequence	Initiation signal	CT Q & CT S	Start indicator	Cycle initiated	Press + visual confirmation	1	Per batch	Batch Record	Start confirmation	Reattempt after checks
29	Monitor Screw Ram pressure	Pressure gauge	Pressure within limits	Ram output force	CT Q & CT S	Live readout	Within operating range	Digital gauge	Continuous	During op	Batch Record	Monitoring	Stop process if out of range
30	Check material flow at die face	Extruder Die	Flow consistency	Die face output	CT Q	Visual flow	Smooth and continuous	Visual inspection	Continuous	During op	Operator Log	Visual	Adjust settings

31	Check uniformity of extrudate	Extrudate line	Shape and size	Uniformity	CT Q	Pellet shape/diameter	Consistent size	Visual + caliper	5	Hourly	QA Log	Visual & measurement	Adjust die or process
32	Inspect for voids or discoloration	Extrudate	Product quality	Appearance	CT Q	Surface of pellets	No voids/discoloration	Visual	5	Hourly	QA Log	Inspection	Quarantine and investigate
33	Run out residual PE-8	Extrusion Line	Product purity	Absence of prior batch mix	CT S	Extrudate appearance	Clear change	Visual observation	Continuous	Start of batch	Batch Record	Visual clearance	Discard first run; monitor contamination
34	Reset Interlocks	Control System	System readiness	Interlock position	CT S	System signal	Ready/armed	System reset	1	Post-batch	Log Sheet	Reset check	Report malfunction
35	Clean storage drum (wipe)	Storage Drum	Cleanlines	Surface residue	CT S	Internal drum	Residue-free	Lint-free wipe	1	Post-batch	Cleaning Log	Wiping	Repeat cleaning
36	clean Screw Ram with non-metallic scraper	Ram body	Surface cleanlines	Powder adherence	CT S	Ram surface	Residue-free	Scrape and wipe	1	Post-batch	Cleaning Log	Cleaning	Repeat cleaning
37	Clean Die	Die tool	No build-up	Residual clog	CT S	Die face	Clear	Brush + solvent	1	Post-batch	Cleaning Log	Cleaning	Repeat cleaning
38	Clean Cutter	Cutter assembly	No residue	Blade and housing	CT S	Cutter area	Residue-free	Wipe + inspect	1	Post-batch	Cleaning Log	Cleaning	Repeat cleaning
39	Wipe conveyor with anti-static cleaner	Conveyor surface	ESD compliance	Surface cleanlines	CT S	Conveyor belt	Clean and dry	Wipe with cleaner	1	Post-batch	Cleaning Log	Cleaning	Repeat wipe

	40	Complete cleaning and inspection log	N/A	N/A	Documentation	CT Q & CT S	Log filled and signed	100% completed	Visual check of log	1	Pre-shift	Cleaning Log	Documentation	Retrain operator; escalate if incomplete
	41	Power down PLCs and lockout extruder	PLC system	Shutdown sequence	Control power state	CT S	PLC indicators	No power	Power down + lockout tag	1	Post-batch	Shutdown Log	Power check	Delay until confirmed
	42	lockout extruder	Extruder	Safe isolation	Lockout tag status	CT S	Lockout applied	Visible + verified	Tag + checklist	1	Post-batch	Shutdown Log	Lockout	Stop work if not locked