Insensitive Munitions
European Manufacturers Group

Methodology for Assessing the Effects of Explosives Ageing on Munition IM Response.

IMEMTS Symposium, 18-21 May 2015, Rome.

Peter Milner (MBDA UK)

Presentation Outline

- Introduction
  - Insensitive Munitions European Manufacturers Group (IMEMG)
  - Expert Working Group on IM and Ageing
- Description of logic diagram tool and methodology
- Tests and failure modes
- Examples of applications
- Test data review
- Testing gaps
- Conclusions and recommendations

IMEMG Member Companies

IMEMG (Insensitive Munitions European Manufacturers Group)

- Brings together European manufacturing companies working with IM technologies.
- Promotes harmonised international IM policies and standards
- Organises seminars and workshops
- Expert Working Groups (EWG) analyse specific IM technology areas and publish papers/ presentations.

IMEMG Expert Working Groups

Expert Working Groups

- **FCO Test Procedure**
  Marie De Bats
  MBDA.France
- **Computer Models**
  Georg Unterhuber
  Bayern-Chemie
- **Hazard Assessment & Classification**
  Yves Guengant
  Eurenco / HERAKLES
- **Cost & Benefit Analysis**
  Rémi Boulanger
  Nexter Munitions
- **Ageing Effects**
  Peter Milner
  MBDA-UK

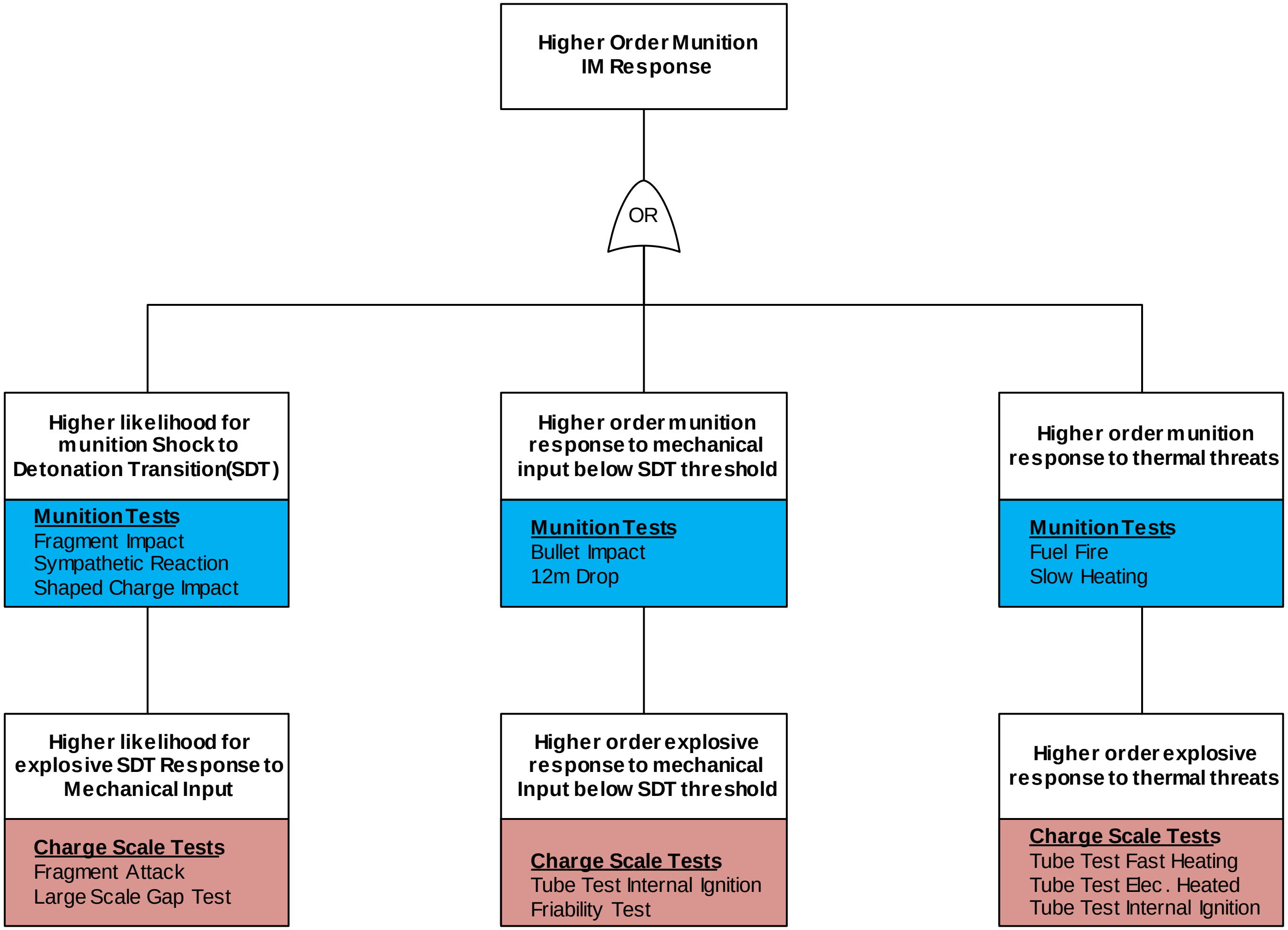
IMEMG EWG – Effects of Explosives Ageing

- Member Companies – AWE, BAE Systems, MBDA UK, Eurenco, MBDA Fr, Nexter, Roxel Fr, Diehl BGT, RWM Italia, Saab Dynamics.
- Remit to undertake analysis based on existing data only.
- Wealth of relevant personal knowledge and experience within group membership
- Initial focus on cast cure PBX compositions as topic of most common interest.
- Requirement for a tool to assess explosives ageing failure modes and capture available data on test results.

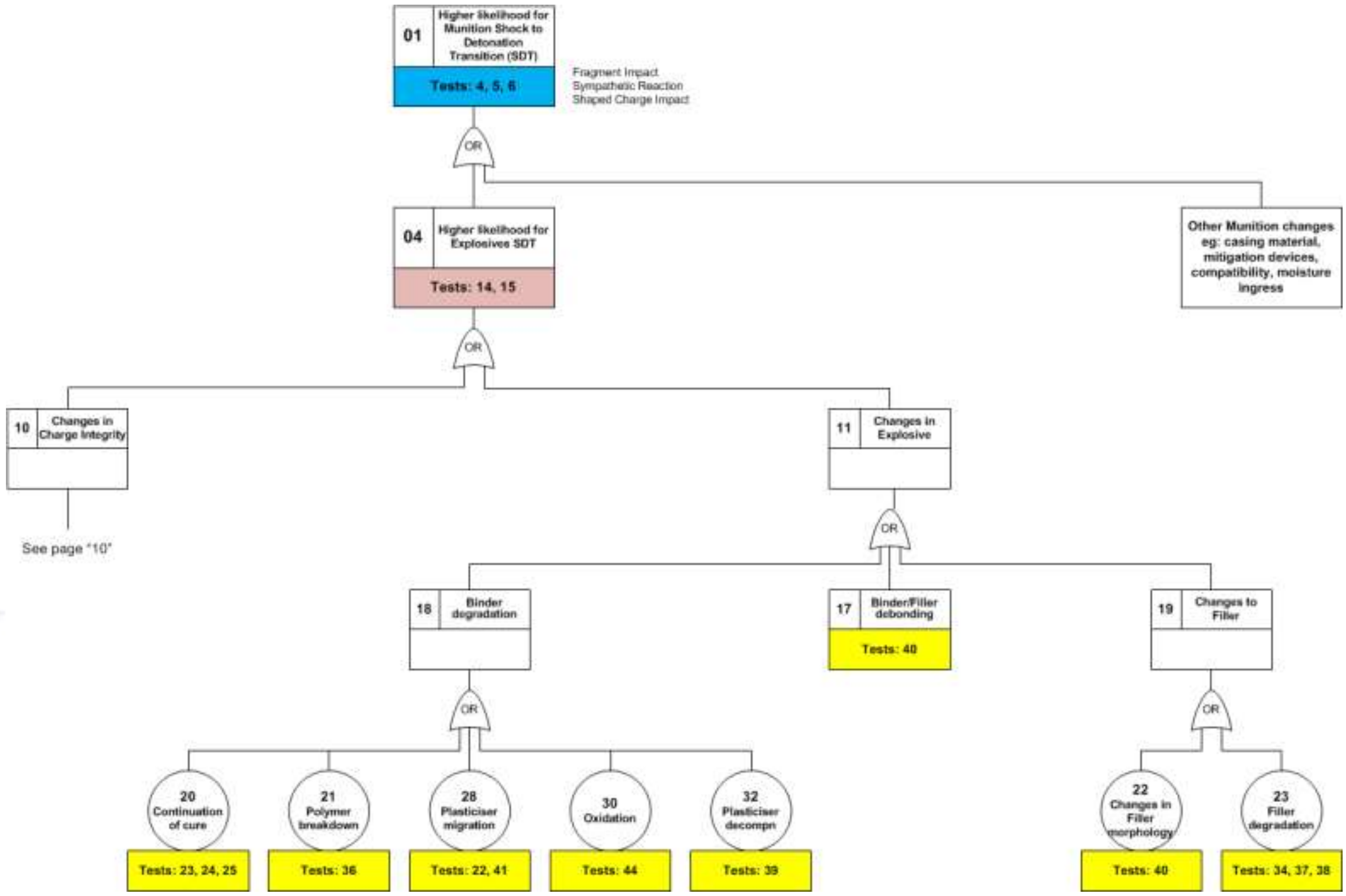
Assessment Tool

- Tool required to:
  - Identify explosives failure modes wrt IM properties
  - Correlate relevant tests and test data.
- FMEA considered (bottom up analysis).
- Logic Diagram in Fault Tree Analysis (FTA) format preferred because:
  - Top down approach from single 'top event'
  - Clear visual links between 'fault events', tests and munition IM response.

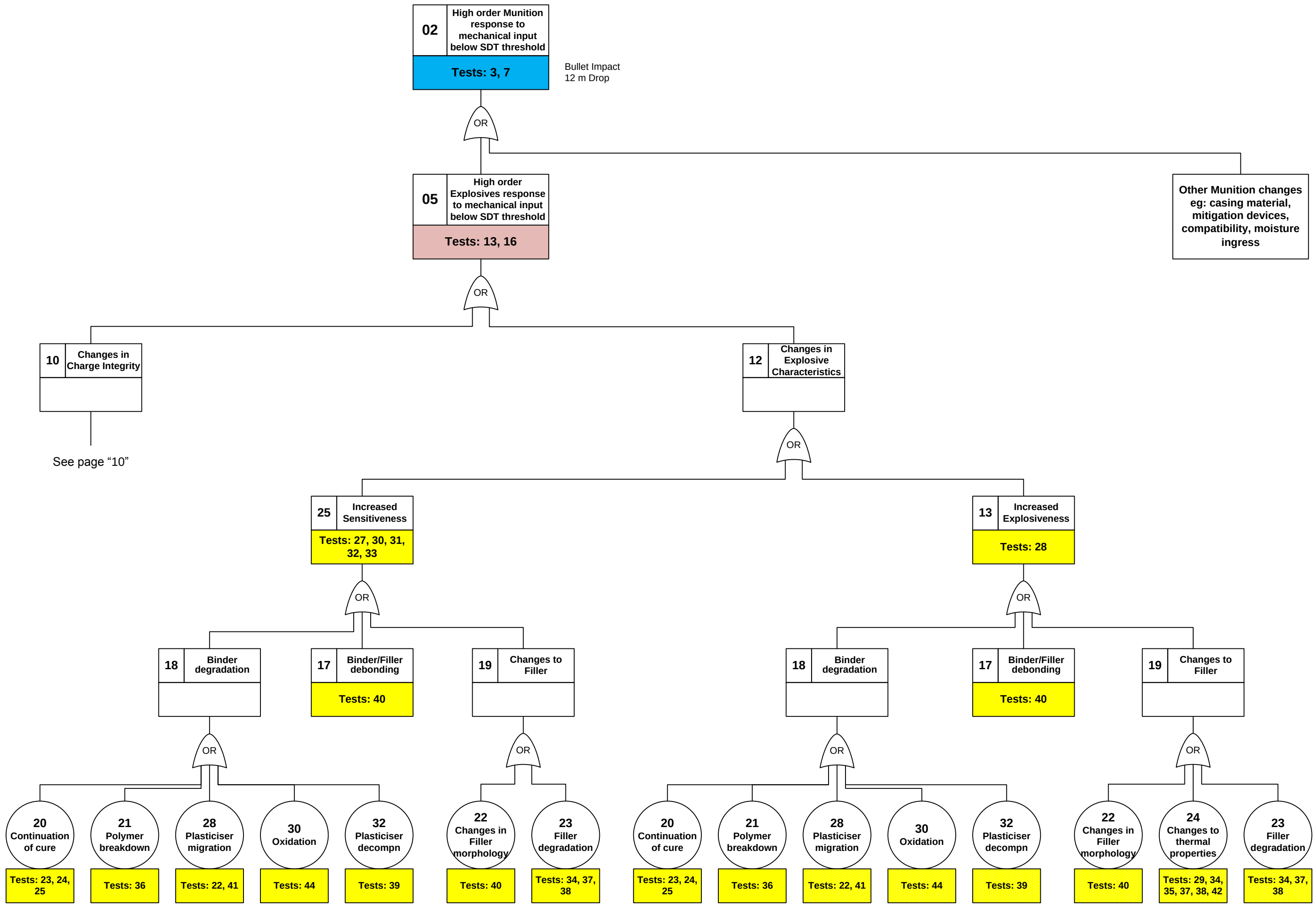
Logic Diagram – Top Level



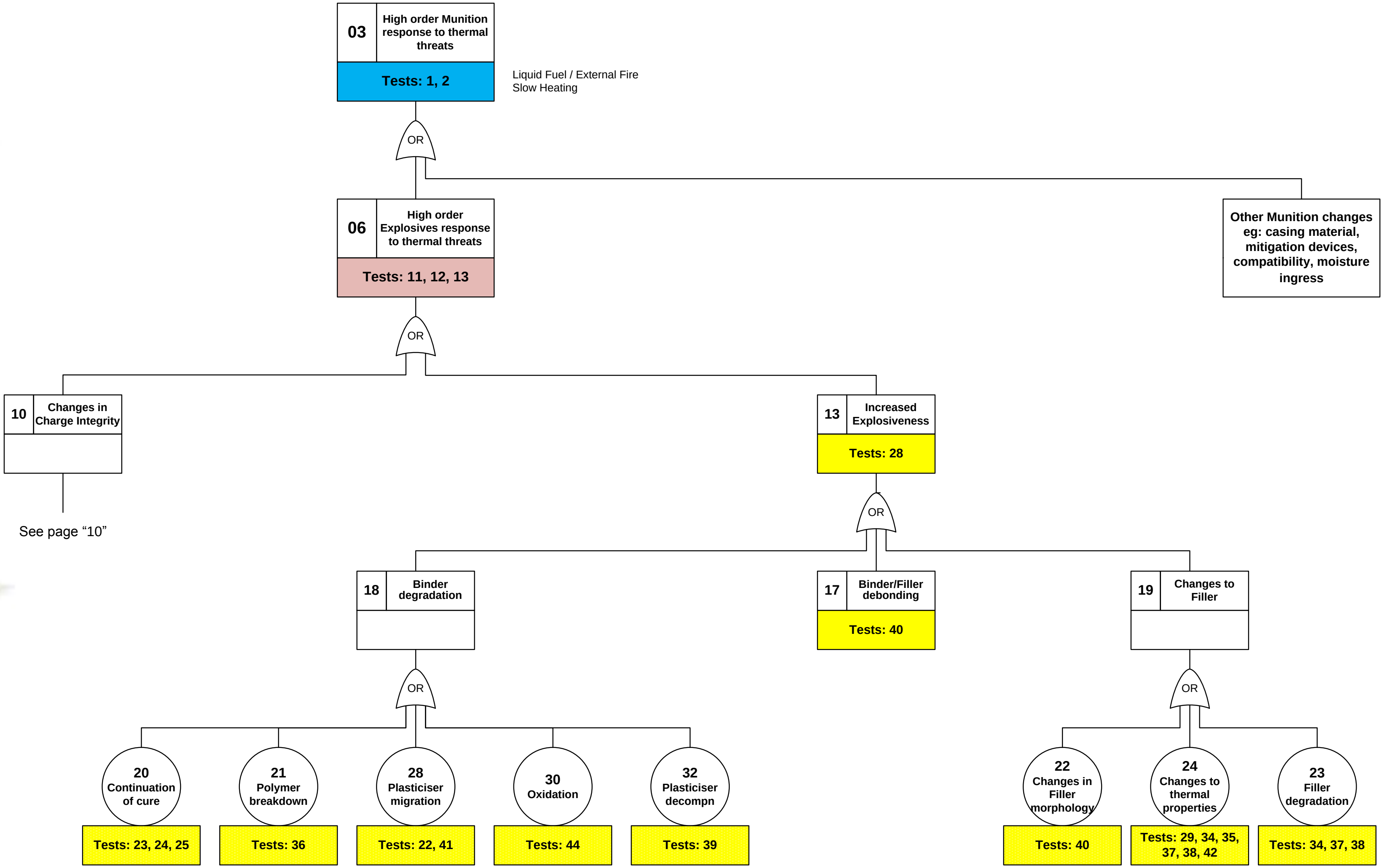
Logic Diagram – SDT



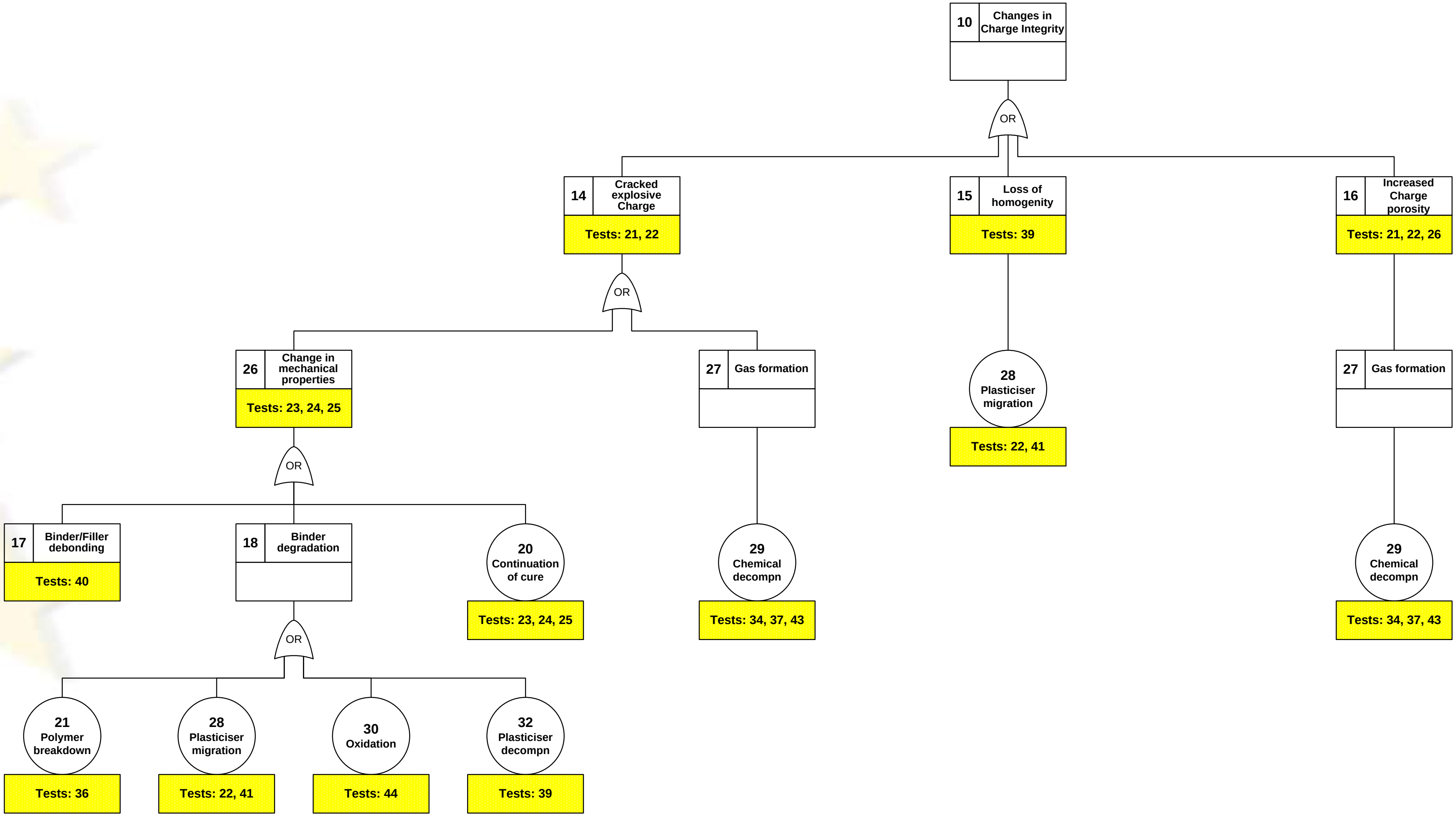
Logic Diagram – Mechanical Impact



Logic Diagram – Thermal Threats



Logic Diagram – Charge Integrity



International Test Comparison (UK/Fr)

	UK REFERENCES			NATO REFRENCES		FRENCH REFERENCES			
Munitions Scale IM Tests						**Munitions Scale IM Tests**			
Ref	**Description**	**Spec.**	**AOP7 - UK**	**STANAG**		**Test**	**AFNOR**	**SME N°**	**AOP7 - FR**
1	Munition Fast Heating			4240					
2	Munition Slow heating			4382					
3	Munition Bullet Impact			4241					
4	Munition Fragment Impact			4396					
5	Munition Sympathetic Reaction			4496					
6	Shaped Charge Impact			4526					
7	Munition 12 m drop Test	Def Stan 00-35							
Charge Scale IM Tests						**Charge Scale IM Tests**			
Ref	**Description**	**Spec.**	**AOP7 - UK**			**Test**	**AFNOR**	**SME N°**	**AOP7 - FR**
11	Fast Heating Tube Test	EMTAP 41	202.01.006						
12	Electrical Heated Tube Test	EMTAP 42	202.01.007						
13	Internal Ignition Tube Test	EMTAP 35	202.01.005						
14	Fragment Impact Tube Test	EMTAP 36							
15	Large Scale Gap Test	EMTAP 22		4488					
16	Friability Test	UN 7 (c) (ii)				Friabilité	NF T70-524	82	201.08.004
Explosive Charge / Material Tests Tests						**Explosive Charge / Material Tests Tests**			
Ref	**Description**	**Spec.**	**AOP7 - UK**			**Test**	**AFNOR**	**SME N°**	**AOP7 - FR**
21	Radiography								
22	Visual of sectioned charge								
23	Tensile strengh / elongation		102.01.001	4506		Propriétés mécaniques en traction	NF T70-315		
24	DMA		102.01.025	4540					
25	Shore A hardness					Dureté Shore	NF T70-316		
26	Density		102.01.070			Masse volumique globale	NF T70-358		102.02.012
27	Rotter Impact	EMTAP 1A	201.01.001	4489					
28	Small Scale Explosiveness	EMTAP 1D	201.01.003						
29	Temperature of Ignition	EMTAP 3	202.01.002	4491		Température d'auto inflammation par chauffage progressif	NF T70-504	47	
30	BAM Impact	EMTAP 43		4489	Annex C	Indice de Sensibilité à l'Impact - BAM	NF T70-500	14	201.01.001
31	BAM Friction	EMTAP 44		4487	Annex A	Indice de Sensibilité à la Friction - BAM	NF T70-503	16	201.02.001
32	Mallet Friction	EMTAP 2							
33	Rotary Friction	EMTAP 33	201.02.001						
34	DSC Analysis		102.01.050	4515	test B2	DSC	NF T70-368		
35	ARC Test								
36	Sol-Gel/ Crosslink Density			4581		Densité de réticulation			
37	Vacuum Stability			4556		Stabilité sous vide	NF T70-531		
38	HFC Analysis			4582					
39	Composition Analysis					Dosage des constituants d'explosifs secondaires	NF T70-337		
40	Microscopic Examination								
41	Plasticiser Content								
42	One Dimensional Time to Explosion								
43	Explosives Compatibility			4147		Compatibilités	NF T70-516/517		
44	Antioxidant Level								

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Links Between Failure Modes and Material Tests

		Explosive Material Tests																							
		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
		Radiography	Sectioned charge	Tensile	DMA	Shore A hardness	Density	Rotter Impact	Small Scale Explosiveness	Temperature of Ignition	BAM Impact	BAM Friction	Mallet Friction	Rotary Friction	DSC Analysis	ARC Test	Sol content / Cross link density	Vacuum Stability	HFC Analysis	Compositional Analysis	Microscopic Examination	Plasticiser Content	One Dimensional Time to Explosion	Explosives Compatibility	Antioxidant Level
Explosive Material Failure Modes																									
13	Increased Explosiveness								X																
14	Cracked Explosive Charge	X	X																						
15	Loss of Homogeneity																			X					
16	Charge Porosity	X	X				X																		
17	Filler/Binder Debonding																				X				
20	Continuation of Cure			X	X	X																			
21	Polymer Breakdown																X								
22	Changes in Filler Morphology																				X				
23	Filler Degradation														X			X	X						
24	Changes to Thermal Properties									X					X	X		X	X				X		
25	Increased Sensitiveness							X			X	X	X	X											
26	Change in Mechanical Properties			X	X	X																			
28	Plasticiser Migration		X																			X			
29	Chemical Decomposition														X			X						X	
30	Oxidation																								X
32	Plasticiser Decomposition																			X					

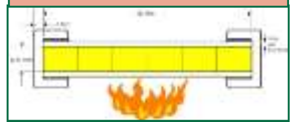
Use of Logic Diagram

TOP DOWN
Investigation
Assessment

Full Scale Tests

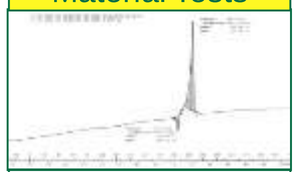
Order of Costs
~ £1M

Charge Scale Tests



Order of Costs
~ £100k

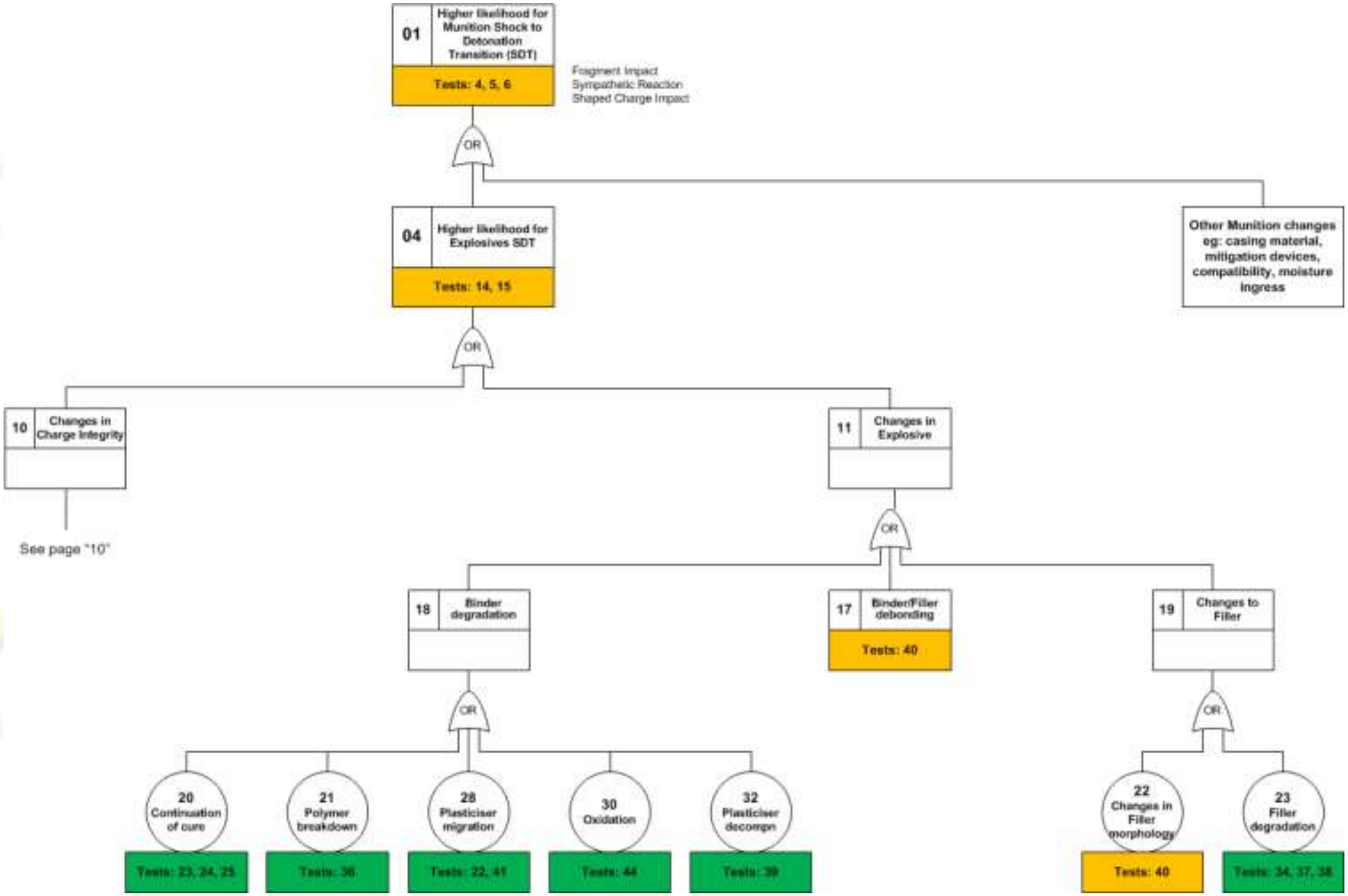
Material Tests



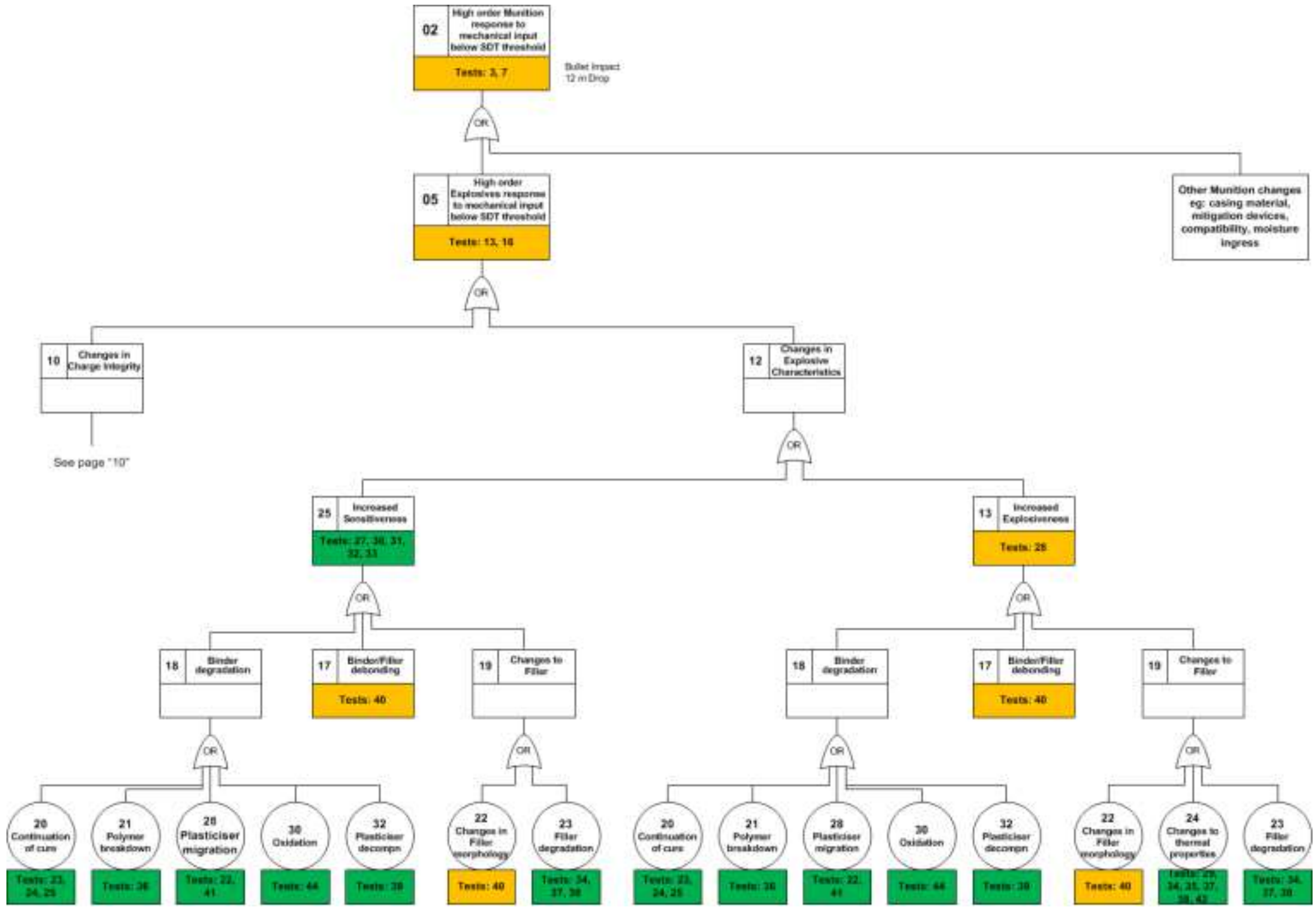
Order of Costs
~ £10k

BOTTOM UP
Risk Reduction
Qualification
Life Extension

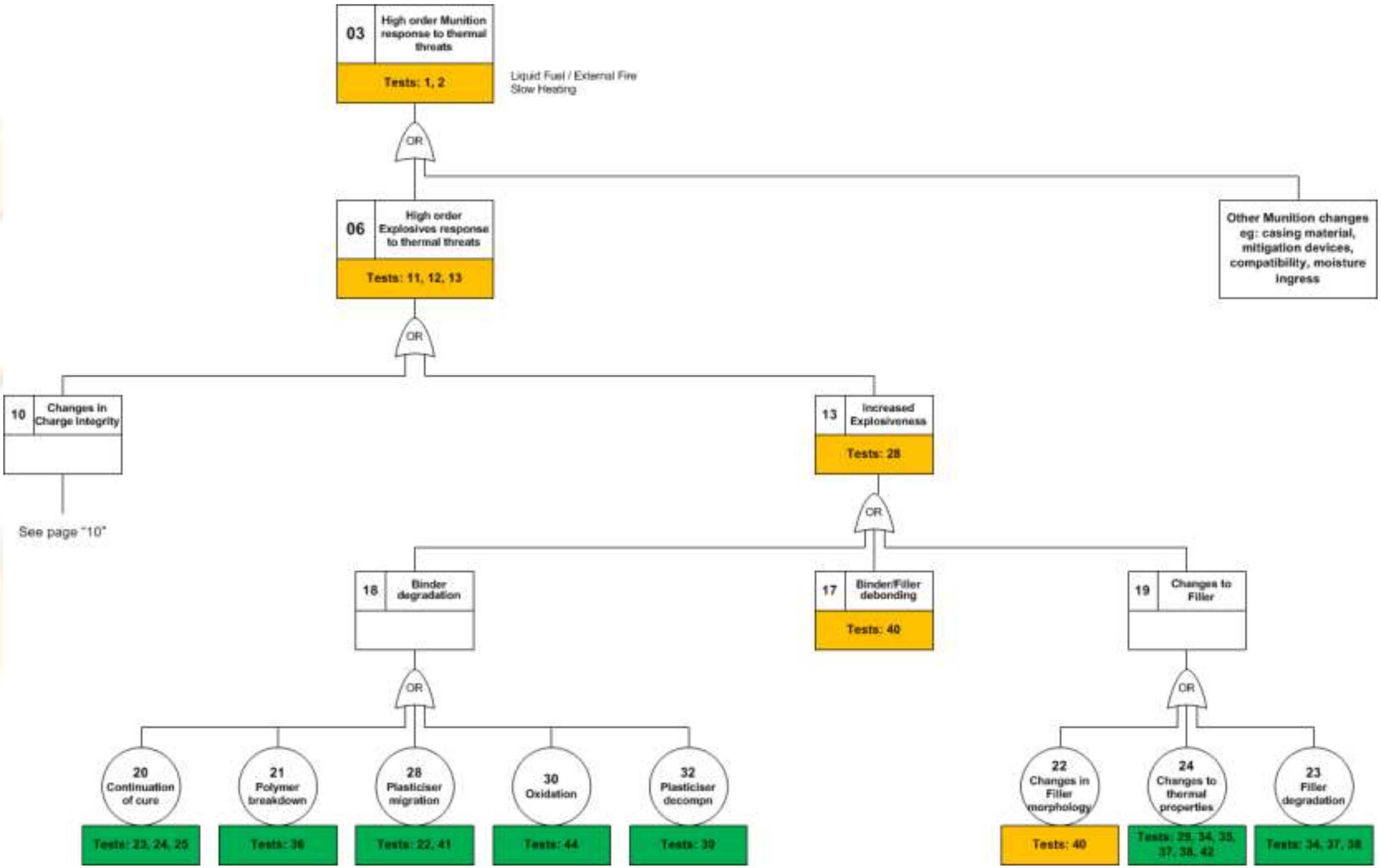
Storm Shadow SALE Test Coverage - SDT



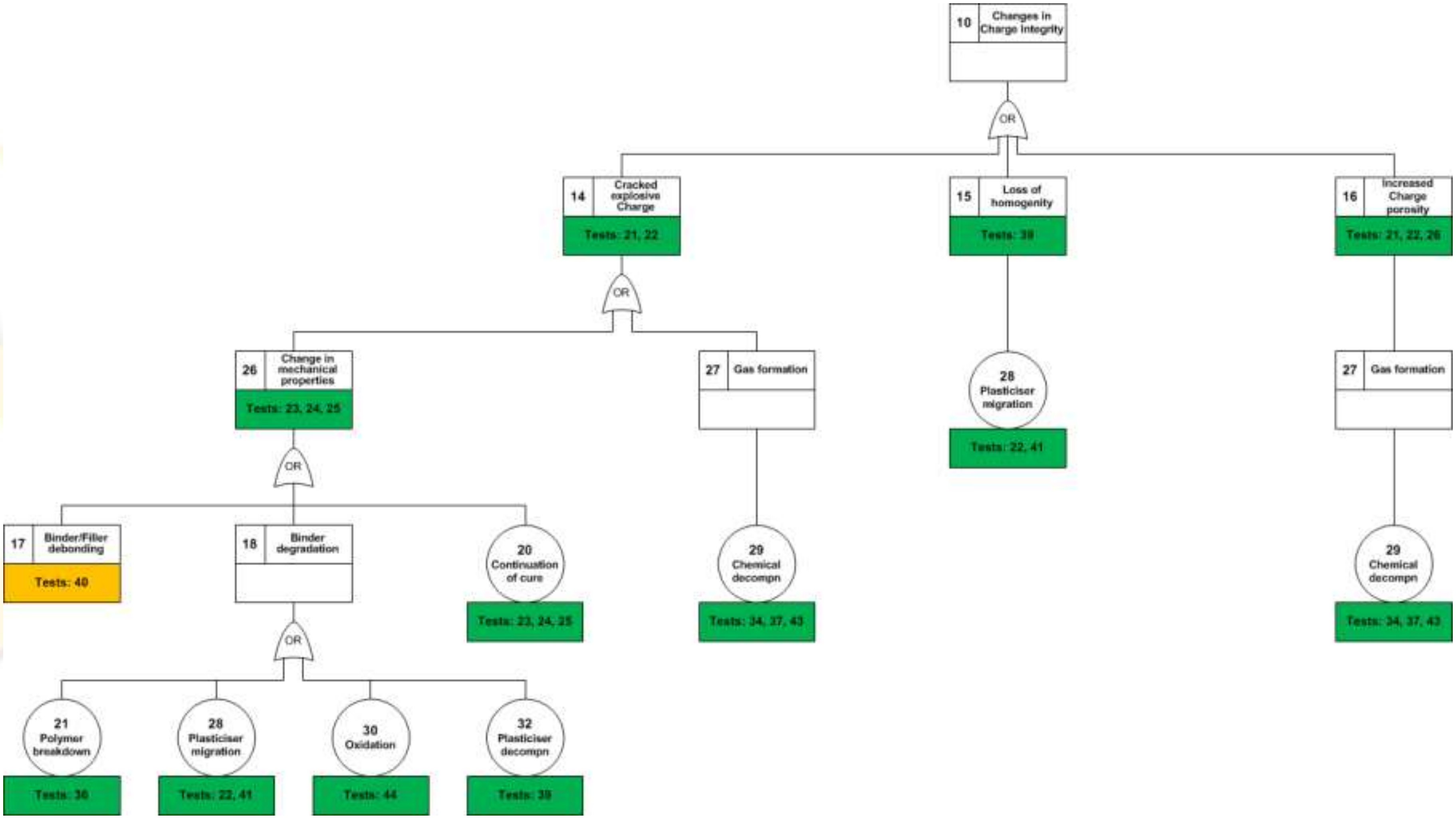
Storm Shadow SALE Test Coverage – Mechanical Impact



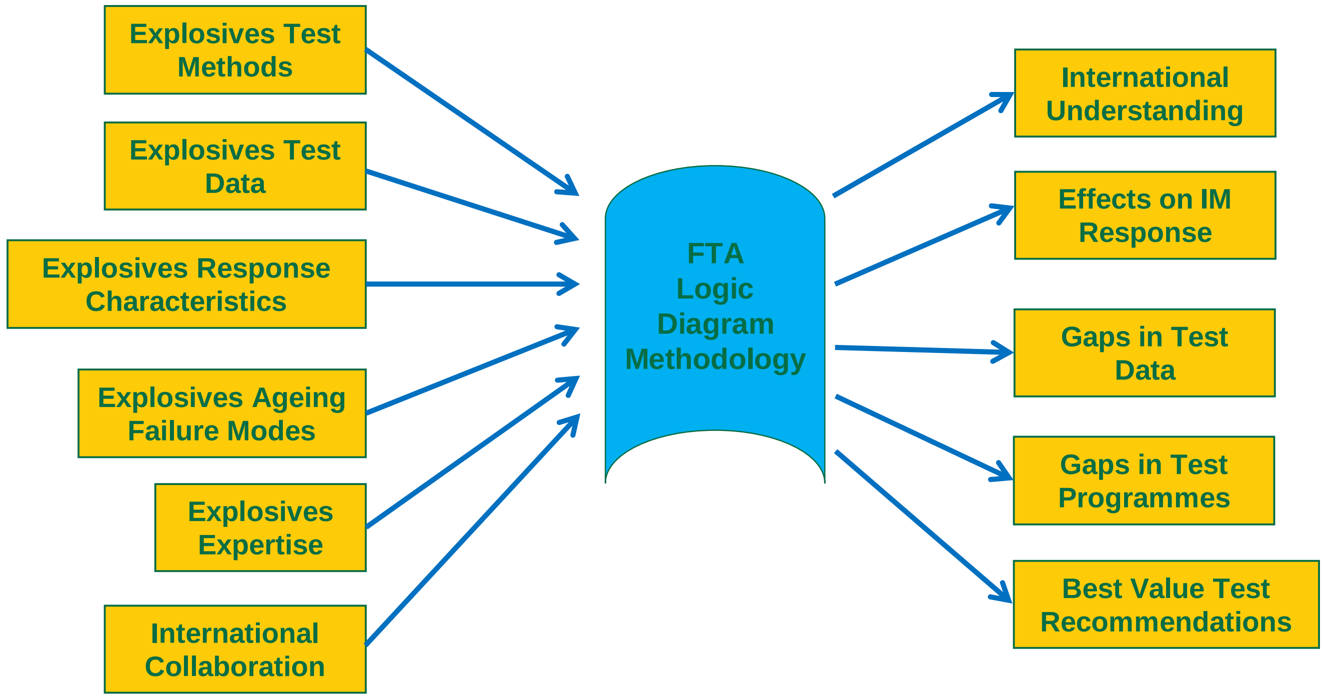
Storm Shadow SALE Test Coverage - Thermal Threats



Storm Shadow SALE Test Coverage – Charge Integrity



Methodology Flow Diagram



Benefits of Logic Diagram Methodology

- Holistic (not fragmented) approach
- Provides framework for sharing expertise
- Focuses on failure modes – not tests
- Illustrates links between material properties and IM response.
- Correlates failure modes and tests
- Collates international test methods
- Identifies the most valuable tests
- Provides rationale for test programmes and identifies gaps
- Can be employed for purposes of characterisation or investigation

Available Test Data

- Data from testing of aged explosives and munitions was collected
- Test data included full scale IM trials, charge scale tests and material tests.
- Data sourced from conference presentations, published papers and the collective experience and knowledge of group members.
- The purpose of test data collection was to:
  - Review current body of evidence regarding impact of explosives ageing on IM response.
  - Examine specific examples of degradation seen in testing
  - Identify gaps or weaknesses in testing and test methods

Full Scale Test Data

Organisation	System	Energetic Material	Ageing Conditions	Munition Changes	IM Test	IM Response
DSTO Australia	Penguin Warheads	PBXN-109	70°C for 12 months	Liner exudation Charge cracking Fuze-well distortion	Bullet impact (20mm AP 900m/s) Sympathetic Reaction	Type V to IV No change
US Navy	BLU-110 1000lb bombs	PBXN-109	20 years real time		Bullet impact (Triple 0.5" 845m/s) Fuel Fire	No change (IV) No change (IV)
US Army	Dev W/Hd	PBXN-109	60°C for 72 weeks (18m)		Fragment impact (STANAG 4496 1830 m/s)	No change (IV)
DRDC Canada	105mm Artillery Shell	CX85 (HMX/Binder 84/16)	70°C for 50 weeks		Bullet impact (0.5" 850 m/s)	No change (IV)

Charge Scale Test Data

Organisation	Programme	Energetic Material	Ageing Conditions	Test	Response
US Navy	RS-RDX Round Robin	PBXN-109 with RDX Types I and II variants	70°C for 12 months	LSGT shock sensitivess	Increase for RDX Type II variants
Eurenco	Eurenco	PBXN-109 variants with RDX Type with different levels of HMX	60°C for 3 months	LSGT shock sensitiveness	Increase for 5%HMX co-crystallized, no change for 0.5% HMX co-crystallized, no change for 2% HMX mechanically added
BAE Systems DOSG	DOSG	ROWANEX 1400	Elevated temperature and duration representing 20 years real time	LSGT shock sensitiveness Fast heating tube test Internal ignition tube test	No change No change Slight increase in explosiveness
Eurenco	Eurenco	ORA 86B and B2214B (HMX-based PBXs)	60°C for 24 months	Friability Bullet impact 12.7mm (AOP7 201.05.002)	No change No change

Material Level Test Data

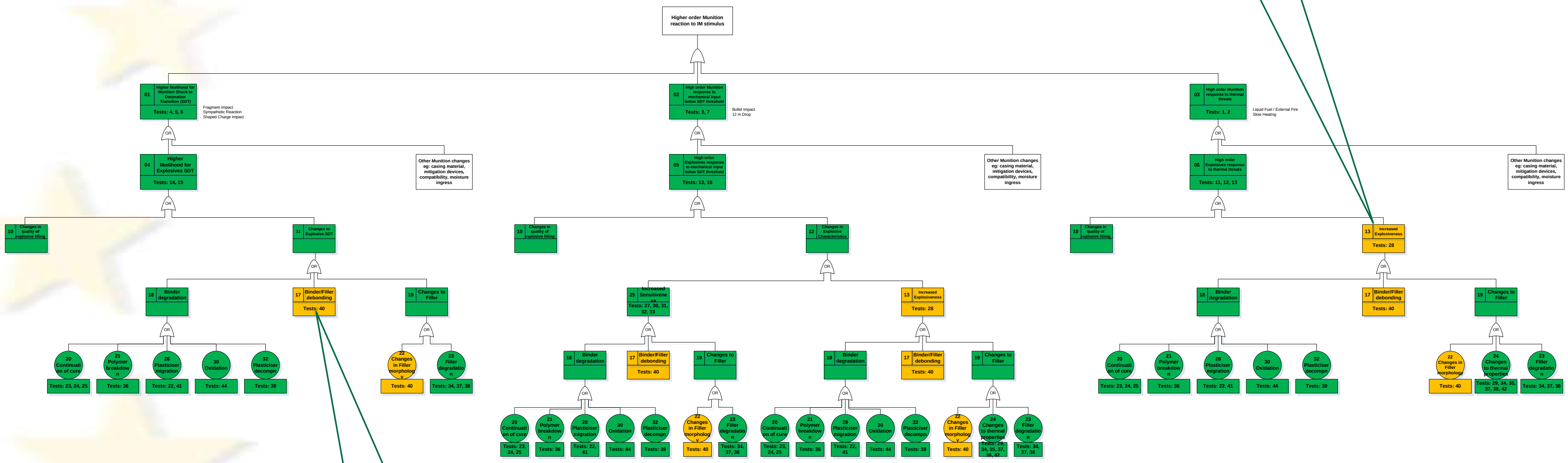
- Large amount of data reviewed, both from open literature and project reports. Broad summary as follows:
  - Little or no significant change due to ageing seen in the following tests:
    - Physical: Sectioning, radiography,
    - Chemical: nitramine/binder/plasticiser content, sol fraction, vacuum stability, DSC,
    - Small scale hazard: impact/ friction sensitiveness, temperature of ignition
  - The following changes due to ageing have been noted:
    - Mechanical: some increase in hardness, increase in tensile strength, decrease in elongation, increase in modulus,
    - Chemical: anti-oxidant depletion.
  - The effects of real time ageing less than the corresponding accelerated ageing period

Test Data – Summary

- Most common explosive assessed is PBXN-109. Reports are generally not specific regarding details of RDX source and composition.
- Full scale IM test results reviewed suggest no significant effects due to ageing.
- Charge scale data predominantly LSGT and indicates increase in shock sensitiveness with some nitramine sources.
- Material tests generally show a decrease in max strain and an increase to some extent in max stress, modulus and hardness. This has not been seen to have a significant impact on sensitiveness or explosiveness.

Test Data – Coverage

Gaps
Small Scale
Explosiveness



Gaps
Filler Morphology/
Binder Debonding.
(Microscopic Exam.)

Overall Conclusions & Recommendations

- Logic diagram illustrates links between IM response, degradation mechanisms and tests.
- Enables constructive discussion and sharing of expertise.
- Elements of the methodology able to influence thinking on test programmes for qualification, life extension, assessment of manufacturing changes etc.
- Tests should be based on assessment of potential failure modes, and not a repeat of previous test programmes.
- Link between failure modes and international test methods could promote a greater acceptance of foreign test data.
- Consideration should be given to further use of microscopic examination and small/charge scale explosiveness tests for aged explosives.
- EWG to apply the same methodology to assess the effects of ageing on melt cast explosives and composite propellants.

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Acknowledgements

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nexter MUNITIONS Nexter Munitions

AWE

SAAB

BAE SYSTEMS

Roxel

MBDA MISSILE SYSTEMS

RHEINMETALL DEFENCE

DIEHL Defence