PERSONAL PROTECTIVE EQUIPMENT

A HANDBOOK FOR CBRNE INCIDENT RESPONDERS

JAMIE BRAYBROOK
DAVE USHER
DOMINIC KELLY

1. Introduction

1.1 Purpose of this Handbook

This Handbook describes Personal Protective Equipment (PPE) for personnel responsible for dealing with Chemical, Biological, Radiological and Nuclear incidents.

It is intended to provide a general awareness of the research that has been carried out into PPE and the current issues in the field.

1.2 Acknowledgements

The Handbook was created by Jamie Braybrook, Dave Usher and Dominic Kelly of CBRNE Ltd.

The underlying research work was carried out within Project EDEN, funded by the Seventh Framework Programme of the European Union.

1.3 Contacts

If you have any queries or comments regarding the content of this Handbook, please contact Dominic Kelly, Managing Director, CBRNE Ltd.

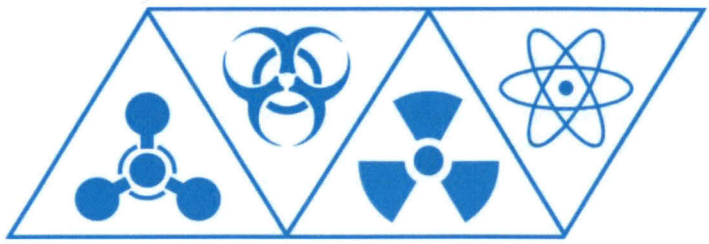
2. Contents

3. Acronyms and initialisms

	Meaning
BS	British Standard
CBRN	Chemical, Biological, Radiological and/or Nuclear
CE	Conformité Européenne
CWA	Chemical Warfare Agent
DSTL	Defence Science and Technology Laboratory
EDEN	End-user driven DEmo for cbrNe
EEC	European Economic Community
EU	European Union
FP	Framework Programme
HIV	Human Immunodeficiency Virus
HQ	Headquarters
LEA	Law Enforcement Agency
NIOSH	National Institute for Occupational Safety & Health
PAPR	Positive Air Pressure Respirator
PHE	Public Health England
PPE	Personal Protective Equipment
SARS	Severe Acute Respiratory Syndrome
TIC	Toxic Industrial Chemical
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research)
TR	Technical Report
UK	United Kingdom

4. Summary

Our society faces an ever-increasing threat from the misuse of Chemical, Biological, Radiological and Nuclear materials (CBRN)[1]. They have been used recently by terrorists. We have seen industrial accidents involving them. And global health scares such as Middle Eastern Respiratory Syndrome and Ebola are becoming more frequent.



For this reason, it is important to understand the issues surrounding the development, procurement, selection and use of Personal Protective Equipment (PPE) for CBRN incidents.

This Handbook should not be used to select PPE for a particular incident. Rather, it is intended to inform the reader of the generalities of the subject. It should be of interest to those responsible for procuring PPE, delivering PPE training, managing CBRN incidents and communicating in a CBRN crisis. News agencies and government stakeholders might find it a valuable source of background information.

The Handbook is structured as follows:

- Sections 5 to 9 present some background information on the use and selection of PPE for CBRN incidents. Section 6 focuses on the differences between civilian and military operations
- Annex A summarises three previous EU-funded projects in the area of PPE – IFREACT, I-PROTECT and FRESP
- Annex B contains a flowchart developed in the IFREACT project for selecting PPE for specific types of missions.

[1] It is important to highlight that the 'N' within the CBRN initialism does not refer to the nuclear industry, but to the detonation of atomic devices by an aggressor and the particularly penetrating gamma and neutron radiation (and widespread contamination) that might be produced. Radiation hazards from nuclear terrorism are not covered by this Handbook, but hazards from contamination are addressed in the R category.

5. PPE and CBR Hazards

The term PPE means any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards. It includes:

- A unit constituted by several devices or appliances which have been integrally combined by the manufacturer for the protection of an individual against one or more potentially simultaneous risks
- A protective device or appliance combined (inseparably or otherwise) with personal non-protective equipment worn or held by an individual for the execution of a specific activity
- Interchangeable components that are essential to its satisfactory functioning and used exclusively for such equipment.

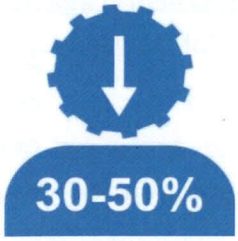
It is impossible to list all the materials that could be considered hazardous, but Table 1 presents some examples, with references to the further information provided in this Handbook. The table is taken from Project IFREACT, described in Annex A.

Table 1: CBR agents [Ref 1]

Agent type		Representative agent(s)	Section
C	Volatile nerve agent (CWA)	Sarin	5.2
C	Persistent nerve agent (CWA)	VX / Vx	5.2
C	Blister agent (CWA)	Mustard gas	5.2
C	Blood agent (CWA)	Potassium Cyanide	5.2
C	Incapacitating agent	Teargas	5.3
C	Toxic Industrial Chemical (TIC)	Ammonia, Boron trichloride, Fluorides, Formaldehyde, Phosphorus trichloride, Hydrobromic acid (Hydrogen bromide), Phosgene, Phosgene oxime, Hydrogen chloride (Hydrochloric acid), Chlorine, Nitric acid, Sulfurous acid, Dimethyl sulfate, Oleum (fuming Sulfuric acid), Sulfuric acid, Arsine, Boron trifluoride, Diborane, Ethylene oxide (Oxirane), Trimethylene oxide (Oxetane), Hydrogen fluoride (Hydrofluoric acid), Hydrogen sulphide, Carbon disulphide, Cyanogen chloride, Hydrogen cyanide (Hydrocyanic acid), Methyl isothiocyanate (Isothiocyanatomethane), Platinum cyanide	5.3
B	Bacterium	Anthrax, Plague, Ebola	5.4
B	Toxin	Botulinum toxin, Ricin	5.4
B	Virus	Smallpox (intentional), SARS (natural/accident), Ebola	5.4
R	Radiological agent	I-131, CO-60, CS-137	5.5

We discuss below some of the implications of the use of PPE against these types of agent. It is important to recognise that PPE cannot be considered in isolation – it must be used in combination with equipment for hazard detection and monitoring.

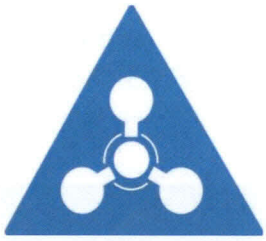
5.1 General Environment



The incident commander will employ risk management techniques to balance the hazard against the wider operational demands. In an operational situation, where momentum is key, he or she must gather the information available and judge the overall threat.

The decision on the protection factor to recommend should take account of the degradation in performance that the operator will experience during the task. It is generally accepted that PPE causes a loss of operational efficiency of between 30 - 50% due to the temperature, humidity, additional strain on the respiratory system, visual impairment and so on.

5.2 Chemical Warfare Agents



Chemical Warfare Agents (CWAs) are designed to restrict and disrupt operations. They can affect everyone whose skin or respiratory system is exposed. CWAs are far more dangerous than Toxic Industrial Chemicals (TICs) (see Section 5.3) but more restricted in manufacture.

In a terrorist incident, the exact CWA present may not initially be known, so the extent of the exposure of first responders requires expert assessment at the scene based *inter alia* on sensors, eyewitness accounts and the symptoms of casualties.

5.3 Toxic Industrial Chemical Hazards

Whereas CWAs are intentionally deployed for inhibiting or harming enemy combatants, the accidental release of TICs can produce similar effects and requires similar protective regimes.

The level of protection required by a TIC incident, and the procedure for responding to it, will be determined by the risk assessment performed at the scene. The dynamic nature of the risk (caused for example by more material being released, or some being consumed by fire) means that these risk assessments must be continuously reviewed. Thus, there will be a permanent need for monitoring and detection, despite the nature of the hazardous material having been inferred from existing knowledge about the incident location.

Moreover, the investigation of an incident could lead to it being upgraded to a criminal investigation, which (as for CWAs) might dictate the use of certain types of PPE.

5.4 Biological Hazards

Biological hazards vary in the way they transfer from host to host – some by inhalation and ingestion, others through skin cuts or abrasions. The hazard presented to first responders and medical staff by blood-borne viruses such as HIV, hepatitis and viral haemorrhagic fever is unrelated to terrorism.

It is generally more difficult to detect biological hazards with responder-borne equipment than other hazards. A higher risk must be assumed and therefore a higher level of PPE is indicated.

At the height of the global Ebola outbreak, Public Health England (PHE) produced a factsheet for the UK Police Force offering advice for those who have been exposed to an infected person [Ref 2]. Table 2 is an extract, offering guidance and control measures for PPE. It is an example of the type of simplified guidance that can be produced when the nature of the hazard is certain.

Table 2: PHE guidance and control measures regarding PPE[2]

Control measures	
Policing activities with no physical contact (eg interviewing people)	**No additional PPE required**
Policing activities with physical contact (eg arrest/restraint) No symptoms	**Standard universal precautions apply:** Hand hygiene, double gloves
Policing activities with physical contact (eg arrest /restraint) Suspect case only symptom: High temperature/fever	**Standard universal precautions apply:** Hand hygiene, double gloves
Policing activity with physical contact (suspect case symptoms might include: fever, vomiting, diarrhoea, bleeding). Occurrence of this scenario is considered remote, but could occur in custody* if a detainee becomes unwell and requires first aid or support while awaiting medical attention or evacuation	**Standard precautions apply:** Hand hygiene, double gloves, plastic apron **PLUS** Fluid repellent surgical facemask**, eye protection

** There is no requirement for a Filtering Face Piece (FFP3) mask but if one is available, it can be used in lieu of a surgical mask. In such circumstances, fitting of the FFP3 mask is NOT required, as Ebola is not transmitted through the air. The mask is simply used to prevent splash incidents by protecting the nose and mouth.

[2] Contains public sector information licensed under the Open Government Licence v3.0 – see http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/

5.5 Radiation hazards

Radioactive material is difficult to identify and locate without suitable detection equipment. Direct, on-scene detection of neutron radiation is rather more problematical than for gamma radiation (which is readily achievable) but the presence of neutrons can be inferred from the specific gamma energies measured using hand-held gamma spectrometers.

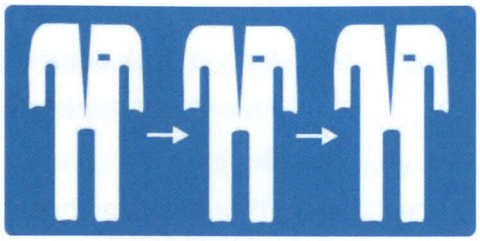
PPE can protect against alpha particles and to some extent against beta radiation, but generally not against gamma or neutron radiation. So the choice of PPE must be informed by readings from suitable detection equipment.

6. Military v Civilian PPE

The CBRN incident responder community has traditionally depended on the military for PPE technology. However, the different operating regimes mean that military equipment might not meet civilian operational requirements.

Moreover, Directive 89/686/EEC [Ref 3] does not apply to PPE procured and used by the military or by Law Enforcement Agencies (LEAs) and so there can be confusion when procedures are dictated by a combined emergency doctrine. These issues are discussed further in Section 8.

6.1 Use



An organisation's Standard Operating Procedures (SOPs) will directly influence how PPE is procured and used. For example, military CBRN suits made from material enhanced with layers of carbon have been shown at UK Government facilities to reduce the penetration of CWAs and meet the requirement for strength and durability. This may not however be adequate for particularly aggressive industrial chemicals that could degrade the protective properties of the material.

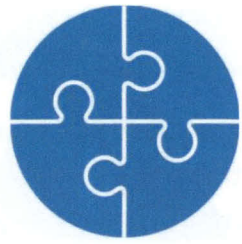
Similarly, for a military deployment, the SOPs might require the PPE wearer to change protective suits frequently. But this is not practicable for a police force responding to a terrorist incident, where hazardous materials have been released, nor for Fire and Rescue teams responding to an industrial spill.

6.2 Testing and Licensing

Research facilities such as Dstl in the UK and TNO in the Netherlands have spent many years testing PPE to the standards required for defence and emergency services.

Dstl has created the Easy Access Intellectual Property scheme to promote new ways of sharing intellectual property to make it easier for researchers and industry to work together [Ref 4]. An example of this type of collaboration is the Dstl / Frazer-Nash Lightweight expedient respirator [Ref 5]. The joint development of future concepts with industry will allow access to world-leading test facilities.

7. System Integration - Guidance



All of the items comprising the PPE 'ensemble' must be fully integrated. For example, the hood of the suit must create an accurate seal around the respirator. Even if a single item is effective against a CBRN hazard via a particular pathway (such as respiration or skin contact), it is not fit for purpose if its function is compromised when used with other components.

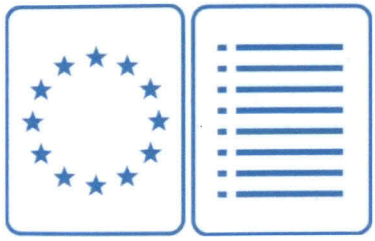
As an example, a permeable PPE suit should:

- Fit with a respirator
- Support an internal and external breathing air system
- Fit with task equipment
- Provide a complete cover-up
- Be difficult to tear
- Have flash and heat resistance
- Have a long shelf life and use life
- Permit normal clothing beneath
- Be water resistant
- Provide a layered system
- Absorb gases as they pass into the suit
- Absorb liquids that penetrate the outer layer
- Provide a complete seal with respirator
- Have Zip or Velcro fastening
- Provide for adjustments at ankle and wrist with limited bellows effect
- Have its reliability tested against a realistic challenge
- Be easily cleaned

Note that PPE is a system that works in conjunction with others, such as sensors. Understanding the associated monitoring and detection requirements as well as the threat is essential for the correct selection of PPE.

8. Procurement and standards

EU Directive 89/686/EEC [Ref 3] provides consistency for the manufacture, procurement and safe use of PPE. It covers the following areas:



- Respiratory protective devices
- Protective clothing
- Protective gloves
- Footwear protection against chemicals
- Ergonomic principles
- PPE testing methodology

The European Commission maintains guidelines to ensure the consistent application of the Directive by all stakeholders. The CE and EC mark indicates conformity to it.

PPE designed and manufactured for military or police purposes is used exclusively within specific military and law enforcement environments and is not covered by the Directive. However, the Directive does cover PPE that can be used by military or police forces, but which is not specifically designed for them. It is important to note that firefighters are not considered as armed or police forces, and yet the PPE equipment they use falls in line with the Directive.

The Directive also applies to any system sold in conjunction with PPE to connect it to an external device. This is regarded as an integral part of that PPE even if the system is not worn or held permanently by the user for the full period of risk exposure.

Table 3 lists the standards that must be met by manufacturers. The evaluation and selection of protective ensembles should be based on a complete understanding of their design, durability, strength, overall performance and protection factors. Budgets and project timelines will determine whether the equipment is acquired commercially or must be specially developed.

Table 3: Product standards

PPE	EU standards		UK and other standards
Respiratory protective devices	EN12941:1998/A2:2008 EN 14387:2004 +A1:2008 EN 13274-7:2008	EN403:2004 EN 149:2001+A1:2009 EN 143:2000/AC:2005	BS 8468-1: 2006 BS 8468-2: 2006
Protective clothing	EN943-1:2002 EN13982-1:2004 EN13034:2005 EN 14605:2005 +A1:2009 EN 1073-2:2002	EN14325:2004 EN14786:2006 EN ISO 13982-2:2004 EN ISO 6530 :2005 EN9431:2002/AC:2005	BS 8428:2004 BS 8467:2006 CEN TR 15419:2006 ISO 22608:2004

PPE	EU standards		UK and other standards
Protective gloves	EN421:1994 EN340:2003 EN 374-1:2003	EN374-2:2003 EN 374-3:2003	
Footwear protecting against chemicals	EN13832-1:2006 EN13832-2:2006 EN 13832-3:2006		
Personal protective equipment – Ergonomic principles	EN 13921:2007		
PPE testing methodology	EN13274-1:2001 EN13274-2:2001 EN 13274-3:2001	EN863:1995 EN 420:2003+A1:2009	

The procurement tool developed in the IFREACT project has a function called 'Define Success' which gives examples of the criteria and functionalities for PPE [Ref 6]. Table 4 lists the design, performance and durability of ensemble components that meet different requirements. Subsequently, the solution might be judged on quality or cost. For example, PPE to protect against the Ebola virus could be a costly Gas Tight Suite and breathing apparatus, when an equally effective solution might be simply goggles, paper mask, rubber boots and gloves, overalls and a single-use plastic apron.

The UK government is addressing the issue of standardisation. For example, since March 2015 there has been a single supplier of Gas Tight Suits to ensure interoperability across all emergency services [Ref 7]. The same policy is being used for the UK Police 'Next Generation' PPE replacement, which should lead to a more integrated solution for all services.

Table 4: PPE requirements

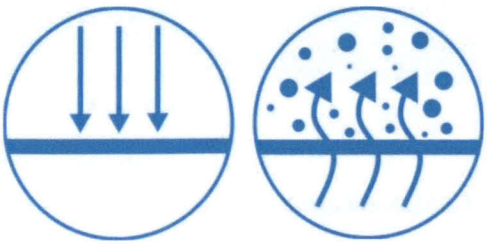
Requirement	The PPE must ...
Functions	• Protect against gas, liquid and particles present in the air • Protect against Chemical agents and specific TICs for 6 hours • Protect against Radiological contamination. Protect against particles > 300 nm for 6 hours • Protect against Biological agents. Protect against particles > 300 nm for 6 hours • Protect against fire (perhaps with added equipment). As a minimum, extinguish after removal of a flame • Protect against liquid splash • Prevent entry of noxious air (but not necessarily be impermeable to air)
Level of protection	• Prioritise protection in this order: respiration > gloves > boots > body

Requirement	The PPE must ...
Communication	• Enable communication with other responders and HQ • Support situational awareness • Allow the user to converse with the victims (to hear and be heard) • Display the role of the user – firefighter, medic, CBRN specialist • Allow the user's face to be seen
Comfort	• Allow the user sufficient mobility to walk, run, crouch and bend etc. • Fit as comfortably as possible • Be as light as possible (< 10 kg in total) • Be easy to put on (< 5 min) and take off (< 10 min, uncontaminated)
Decontamination	• Be easy to decontaminate (especially add-on fastening systems) • Be waterproof, for at least the decontamination time • Protect the decontamination team from gas droplets
Miscellaneous	• Provide enough batteries to allow a full intervention without recharge (or have batteries that are easy and fast to change). Standard operation time: 6 hours • Have training elements that reproduce the same constraints as the final PPE

Consideration must also be given to the full range of tasks carried out by PPE users responding to and supporting a major incident involving a CBRN release. The tasks can be broken down into three main areas, each of which might require a different PPE ensemble:

- First Response
  - Initial response and evacuation
  - Follow up reconnaissance and evaluation
  - Triage and evacuation of casualties
  - Identification and sampling
- Contamination Control
  - Casualty Decontamination
  - Responder Decontamination
  - Equipment Decontamination
  - Cordon control
  - Receiving medical treatment centre contamination control
- Recovery
  - Forensic follow up
  - Post decontamination and clean up
  - Hazard and Waste management

9. Selection



Annex B contains a flowchart (from Project IFREACT) for the selection of PPE for mission use. It is based on the following Classes (as defined in the EU) and Levels (as defined in the US):

Class 1 / Level A (Impermeable) protection should be worn when the highest level of respiratory, skin, eye and mucous membrane protection is needed. For example:

- Self-contained breathing apparatus (NIOSH approved), or umbilical positive-pressure air supplied
- One-piece non-textile multi-ply polymer based laminate, non-breathable gas tight suit.
- Chemical resistant boots and gloves

Class 2 / Level B (Impermeable) protection should be worn when the highest level of respiratory, skin, eye and mucous membrane protection is needed. For example:

- Positive Air Pressure Respirator (PAPR)
- One-piece Non-textile multi-ply polymer based laminate, non-breathable gas tight suit.
- Chemical resistant boots and gloves

Class 3 / Level C (Permeable – non-textile) protection should be selected for vapour/gas and particulate with limited plash protection. For example:

- Full-face negative pressure air-purifying respirator with PAPR options
- Textile based, layered breathable chemical resistant textile based, hooded two-piece suit
- Chemical resistant boots and gloves

Class 3 / Level C (Impermeable – textile) protection should be used for Liquid splash/particulate protection. For example:

- Full-face negative pressure air-purifying respirator with PAPR options
- One-piece non-textile multi-ply laminate, non-breathable
- Chemical resistant boots and gloves

Class 4 / Level D (Permeable) protection should be selected for dust and general industrial soilage protection (non-CBRN specific). For example:

- Direct face filtered respiration
- Textile based, singular layer and breathable one-piece suit
- Suitably protective boots and gloves

Class 4 / Level D (Impermeable) protection should be selected for dust, chemical splash and general industrial soilage protection (non-CBRN specific). For example:

- Direct face filtered respiration

- Non-textile multi-ply laminate, non-breathable
- Chemical resistant boots and gloves

Table 5 indicates the maximum time that operators can spend wearing PPE in different hazardous areas [Ref 8].

Table 5: Maximum working times (from IFREACT)

Responder	Task	Starting time	Duration	Location
Initial responder	Alerting initial reconnaissance, evacuation	5 min	30 min	Warm/hot zone
Professional responder	Sampling and Identification	30 min	30 min	Hot zone
Decontamination responder	Decontamination of victims and responders	30 min	4 hr	Decon area
Cordoning staff	Cordoning of hazard area	30 min	4 hr	Downwind hazard area
Medical personnel on scene	Triage First aid of victims	30 min	2 hr	Warm zone
Mortuary personnel	Performing autopsies	24 hr	4 hr	Medical facility
Forensic team	Collection evidence	4-8 hr	2 hr	Warm/ hot zone
Clean up worker	Clean up of the area	24 hr	4 hr	Hot zone

Table 6 lists the categories of CBRN clothing available to the commander when a decision has to be made. The data in this Table have been used in the simplified PPE selection guide at Annex B.

Table 6: PPE clothing categories (from IFREACT)

Class 1 (or A)	Class 2 (or B)	Class 3 (or C)	Class 3 (or C)	Class 4 (or D)	Class 4 (or D)
Impermeable	**Impermeable**	**Permeable**	**Impermeable**	**Permeable**	**Impermeable**
Fully gas-tight, all challenge protection	Fully gas-tight, all challenge protection	Vapour/gas/particulate / limited splash protection	Liquid splash/particulate protection	Dust and general industrial soilage protection	Dust, chemical splash and general industrial soilage protection
Non-textile multi-ply polymer based laminate, non-breathable	Non-textile multi-ply polymer based laminate, non-breathable	Textile based, layered breathable system	Non-textile multi-ply laminate, non-breathable	Textile based, singular layer, breathable	Non-textile multi-ply laminate, non-breathable
CBRN protective	CBRN protective	CBRN protective	CBRN protective	No specific CBRN protection	No specific CBRN protection
SCBA/umbilical positive pressure respiration	PAPR filtered positive pressure air supply	Mainly negative pressure respiration but PAPR options included in category	Mainly negative pressure respiration but PAPR options included in category	Direct face filtered respiration	Direct face filtered respiration

10. Conclusions

The need to protect responders from incidents involving CBRN materials is recognised across the EU. A range of PPE is available commercially, much of which is closely based upon military equipment. The training and experience of the commander at the scene and the ability to conduct an accurate risk assessment are critical.

This Handbook reviews some of the issues surrounding the selection and use of PPE for CBRN incidents, and describes some of the PPE that is available commercially. We hope it will be of use in providing a background understanding of the field.

11. References

1 Types of CBRN
http://pst.prometech.eu/procurement/preparatory-steps/cbrne-tics-threat-assessment/types-of-cbrn

2 Ebola Guidance to Police Forces on Use of Personal Protective Equipment
v5: 13 February 2015
Health Protection England

3 Personal Protective Equipment Directive 89/686/EEC
21 December 1989

4 Easy Access Intellectual Property
www.gov.uk/guidance/easy-access-intellectual-property

5 Easy Access IP: a respirator
www.gov.uk/government/publications/easy-access-ip-a-respirator

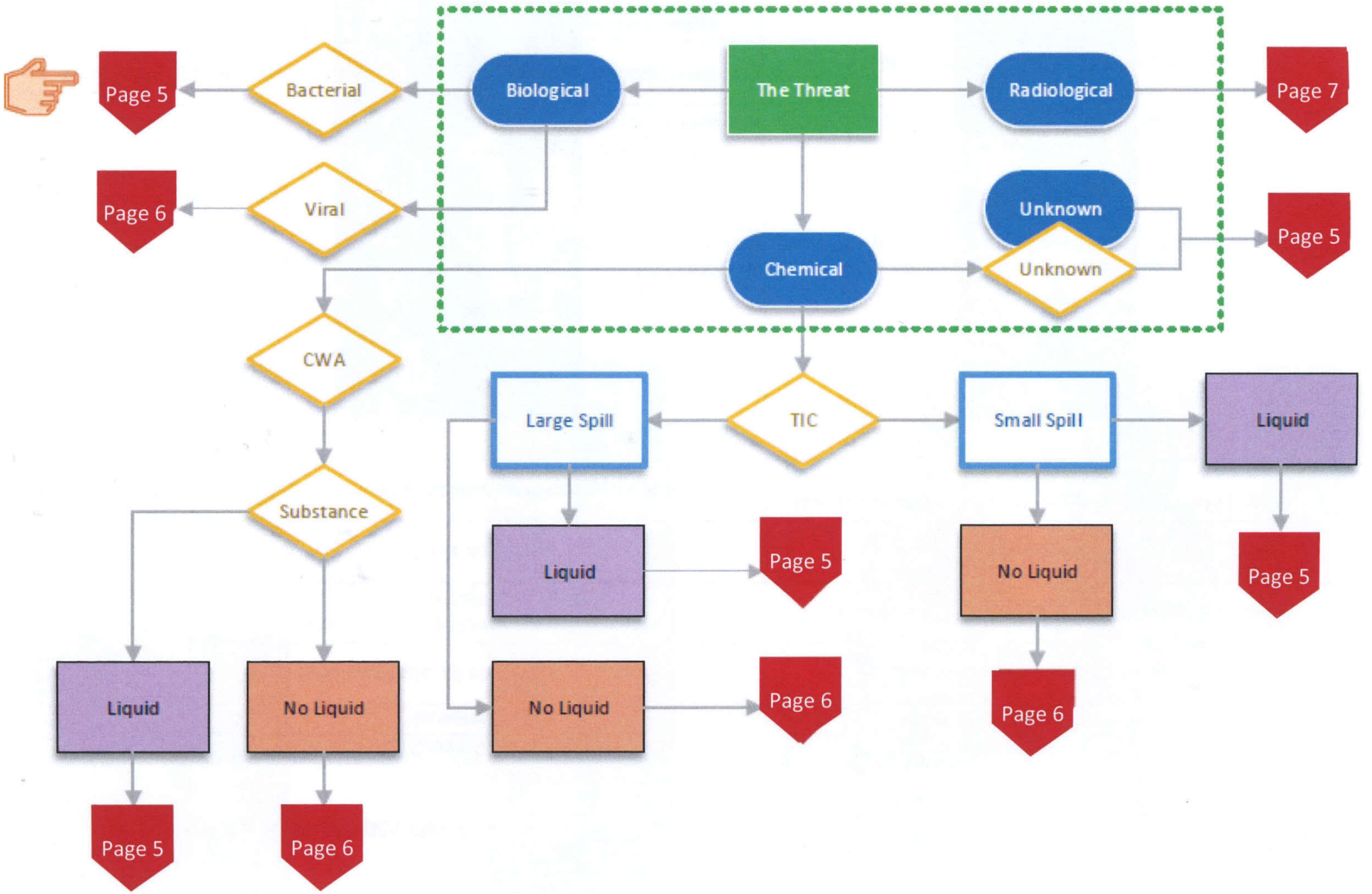
6 Define Success
http://pst.prometech.eu/procurement/procurement-steps/step-2-develop-procurement-strategy/define-success/

7 Home Office: Emergency Services CBRN PPE - Presentation by Pat Robinson, Crown Commercial Service, 11 Nov 2015

8 First Responder Workload
http://pst.prometech.eu/procurement/preparatory-steps/estimation-of-ppe-needs/first-responder-workload/

13. Annex B: PPE SELECTION TOOL

This Tool was developed within Project IFREACT. A more detailed interactive version is available at http://pst.prometech.eu.



PPE Recommendation

Class 1 (or A)	Class 3 (or C)
Impermeable	**Impermeable**
Fully gas-tight, all challenge protection	Liquid splash/particulate protection
Non-textile multi-ply polymer based laminate, non-breathable	Non-textile multi-ply laminate, non-breathable
CBRN protective	CBRN protective
SCBA/umbilical positive pressure respiration	Mainly negative pressure respiration but PAPR options included in category

PPE Recommendation

Class 1 (or A)	Class 3 (or C)	Class 3 (or C)
Impermeable	**Impermeable**	**Permeable**
Fully gas-tight, all challenge protection	Liquid splash/particulate protection	Vapour/gas/particulate/ limited splash protection
Non-textile multi-ply polymer based laminate, non-breathable	Non-textile multi-ply laminate, non-breathable	Textile based, layered breathable system
CBRN protective	CBRN protective	CBRN protective
SCBA/umbilical positive pressure respiration	Mainly negative pressure respiration but PAPR options included in category	Mainly negative pressure respiration but PAPR options included in category

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PPE Recommendation

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Class 3 (or C)
Permeable
Vapour/gas/particulate/ limited splash protection
Textile based, layered breathable system
CBRN protective
Mainly negative pressure respiration but PAPR options included in category