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NATO TEST AND EVALUATION OPERATING PROCEDURES (NTOP) FOR CHEMICAL AND BIOLOGICAL DETECTION, IDENTIFICATION AND MONITORING EQUIPMENT

CHEMICAL POINT DETECTION

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NATO LETTER OF PROMULGATION

27 February 2023

1. The enclosed Allied Engineering Publication AEP-4834, Volume II, Edition A, Version 1 NATO TEST OPERATING PROCEDURES FOR CHEMICAL AND BIOLOGICAL DETECTION, IDENTIFICATION AND MONITORING EQUIPMENT, - CHEMICAL POINT DETECTION, which has been approved by the nations in the NAAG, is promulgated herewith. The recommendation of nations to use this publication is recorded in STANREC 4834.

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CHAPTER 1 INTRODUCTION

1. According to the architecture of the NATO Test and evaluation Operating Procedures (NTOPs) documents defined in Volume I, this Volume II is dedicated to Chemical Point Detection, Identification and Monitoring (noted CPD[1]). The Volume II deals with a common and harmonized Test and Evaluation (T&E) framework, including recommended minimum requirements and best practices for T&E operations.

2. The first priority of NTOPs is to provide guidance to those organizations that define capability requirements, run procurement programs and execute T&E in the Defense sector. The first and most important step is to harmonize or even standardize as much as possible those T&E operations that constitute “formal T&E”, since they are the ones that have the highest potential to directly impact the quality and speed of CPD procurement programs, and as such to help bring the best CPD capabilities into the NATO Defense Forces both faster and more resource-effective. An emphasis on the type of T&E operations that typically constitute formal T&E may also help with the establishment of a common T&E framework that can be used to objectively gauge the distance/gaps between the current state-of-the-art COTS market and the capability/performance requirements of the NATO Defense forces. CPD equipment is then mostly subjected to T&E operations as a “black box” that is tested and evaluated against a set of capability/performance requirements.

3. The second priority of NTOPs is to provide guidance to the Defense industry and research agencies on the T&E of technological developments as part of the R&D process. Such T&E operations could include advanced characterization of the performances of CPD equipment or sensor components.

4. As described in Volume I (see part 2.4.1) concerning the substance forms, the NTOPs documents for CPD take into account:

a. gas and vapor;

b. liquid and solid (bulk substance or contaminated surfaces);

c. aerosol.

5. All the terms used in this document are defined in the glossary above; and the definitions in the ANNEX A).

1 In the whole document, the global acronym CPD is used to refer the chemical detection, identification and (combined) / or (separately) monitoring (DIM) capabilities of point equipment.

CHAPTER 2 TESTING OVERVIEW

1. As described in Volume I, Figure 1 represents the general and complementary approaches for T&E of DIM equipment and systems.

2. Laboratory testing of CPD equipment allows for precise control and reproducibility of both the ambient conditions and the form and quantity of C substance exposure.

3. Field-testing lets the T&E of CPD equipment when trying to detect C substances in more representative/realistic environmental conditions than the controlled ones of laboratory testing. These conditions remain limited and non-exhaustive.

4. Operational testing consists of T&E of the CPD equipment within military environments and scenarios. It is designed to evaluate the effectiveness and suitability of the system with respect to its intended use. Operational Testing is recommended to conduct in partnership with users/militaries in order to meet other specific, user driven DOTMLPFI[2] requirements.

5. For CPD equipment T&E, three main classes of test materials can be used: chemical (C) warfare substances, simulants and interferents.

6. For each CPD equipment T&E, it is generally recommended to always evaluate multiple (more than one) units of each SUT to reduce the impact of outliers during all test operations.

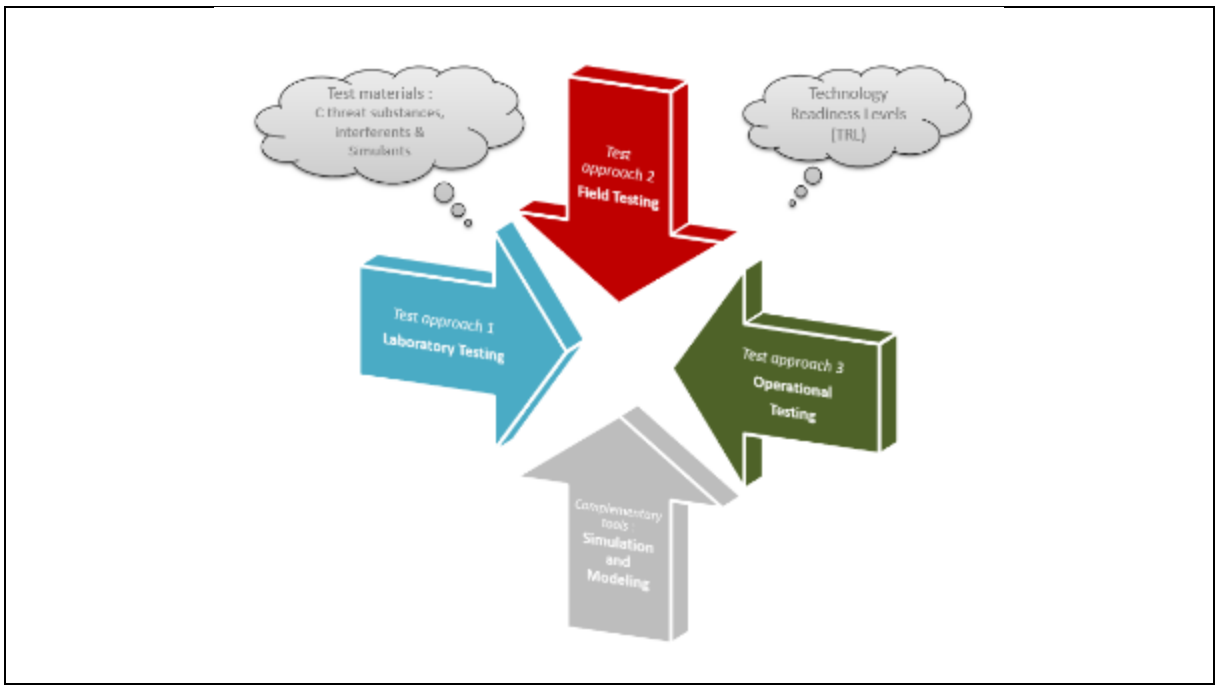

Figure 1: T&E approaches

2 Doctrine, organization, training, materiel, leadership development, personnel, facilities and interoperability.

CHAPTER 3 TEST APPROACH 1 – LABORATORY TESTING

3.1 PURPOSE OF EVALUATION

1. T&E of CPD equipment is a crucial task in the capability development process. Already from the earliest stages of sensor technology development to the final validation ones, there is a need for T&E.

2. The purposes and requirements of the T&E activities will change as the TRL increases. Nevertheless, the fundamental concept and objective of T&E remains, *i.e.* to assess the performance of the CPD equipment in a way that is as realistic and relevant as possible within the limits of what is practical and warranted in light of the current development state and the specific evaluation purpose/needs.

3. Laboratory testing allows for precise control and reproducibility of both the ambient conditions and the form and quantity of C substance exposure.

4. The following fundamental T&E categories are defined for the whole document. The T&E categories depend on several factors including *e.g.* the TRL of the SUT, the T&E objectives and who are involved in the T&E operations.

a. CPD equipment evaluation is performed when the equipment has an established alarm algorithm. Such T&E operations are often formal T&E that considers the SUT as a “black box” and are performed with the purpose of *e.g.* validating the alarm algorithm in the last step of the development or evaluating the performance against requirements in an acquisition process.

b. CPD sensor signal evaluation can be performed without taking into account any defined alarm algorithm. One purpose can be to obtain sensor mono- and/or multidimensional or multivariate data (measurement channel(s), spectra, *etc*.) for different controlled quantities of C substances in order to build alarm algorithms after the tests, or to define response time parameters such as rise time/fall time).

3.2 GAS AND VAPOR

3.2.1 Minimum key parameters for equipment evaluation

1. Table 1 lists the minimum recommended key parameters that should be assessed. These parameters are all interdependent. The report in reference[3] helps for the various following definitions.

2. T&E of the following minimum key parameters should be evaluated for known concentrations of C substance (chemical warfare CWA or not) with or without various and controlled backgrounds: clean background (without interferents) to assess the pure intrinsic performances, and at least some form of simplified real world or simulated background conditions to be representative.

3 Carrano *et al.*, Chemical and Biological Sensor Standards Study, 2004, DARPA, USA

3. These key parameters are detailed in the following parts and in the forms in annexes, which can be the basis for T&E experiments.

Parameters	Details
Sensitivity: minimum detectable substance quantity.	**Alarm level**: concentration level at which the CPD equipment alarms.
Response time: time needed for the CPD equipment to react. Also time for the system to refresh the information.	**Time-to-alarm**: time from exposure at a concentration level corresponding to the one above until the CPD equipment triggers an alarm.
	Clear-down time: time from end of exposure at a concentration level corresponding to the alarm level until the CDP equipment turns of the alarm.
Selectivity: ability of the CPD system of differentiating in the presence of other components.	**False alarm rate FAR**: rate at which the CPD equipment can be expected to trigger false alarms (*e.g.* 1/day, 1/week, 1/year).
	Detection probability P_D: probability that the CPD equipment will trigger an alarm when the C substance is present at a concentration level corresponding to the alarm level.

Table 1: Recommended minimum key parameters for CPD equipment evaluation when performing gas and vapor lab testing.

4. Receiver Operator Characteristics (ROC) curves (see Annex C of D/100 document[4]) can be used to characterize these parameters for one substance at a concentration for a given response time. Such ROC curves can be useful to determine an alarm level and a response time, knowing the LOD and the potential interferents.

3.2.2 Minimum key parameters for sensor signal evaluation

Table 2 shows a minimum list of key sensor signal parameters to recommend to be assessed. Some parameters and details have already been defined (see Table 1).

a. Limit of detection (LOD)

LOD is defined by the ISO[5] as “the true net concentration (or quantity) of component in the material subject to analysis that will lead, with a probability, to the conclusion that the concentration (or quantity) of component in the material analyzed is greater than that of a blank sample”.

b. Rise time / Fall time

Rise time is the time for the measured signal to reach a certain relative value (*e.g.* as illustrated in Figure 2, 90% of a set, often asymptotic, maximum value). Fall time is - on the contrary - the time of measured signal decay from a stable (often high) value

4 Chemical and Biological Warfare Agents (CBWA) Early Warning and Detection Triptych, D/100 (reference document) edition 5, 2011. This D document will be integrated in the future STANREC AEP-4835 on NATO Capability and System Requirements for CB DIM Equipment (in process).
5 ISO International Organization for Standardization definition on ISO 11843-1. Capability of detection. Part 1: Terms and definitions. ISO, Genève (1997).
Moreover, including the probability for false negatives in the definition of LOD leads to a performance characteristic that informs the analyst what (minimum) analyte level the method is capable of detecting with (at least) a probability. It is a parameter, defined a priori, that can be used to select a method or to optimize a method that is already in use. As soon as the method is being used (as intended), it no longer plays a role (or should no longer play a role) in the detection decision which is taken once the result of the measurement is known, that is, *a posteriori*.

when the exposure is removed from the sensor (or v.v.) until it drops to a set relative value (*e.g.* 10% of the initial value).

Parameters	Details
Sensitivity: minimal detectable signal level.	**Limit of detection (LOD)** based on a given statistical method.
Response time: time needed for the sensor to reach a certain signal level.	**Rise time** when a certain quantity of a C substance is presented to the sensor.
	Fall time when the sensor is removed from an exposure of C substance.
Selectivity: ability of the sensor of differentiating in the presence of other components. Evaluation requires post-processing of signals for decision making including threshold(s).	**Detection probability** P_D or probability of successful detection with a threshold signal reached when a C substance is present at a known concentration.
	False positive probability P_{FP} with respect to a given threshold of sensitivity and associated rise time: mistaken detection probability (events per unit time) at which the sensor mistakenly detects the presence of the substance when none is present.
	False negative probability P_{FN} with respect to a given threshold of sensitivity and associated rise time: missed detection probability (events per unit time) at which the sensor misses to detect the presence of the substance that is yet present.

Table 2: Recommended minimum key parameters for sensor signal evaluation when performing gas and vapor laboratory testing

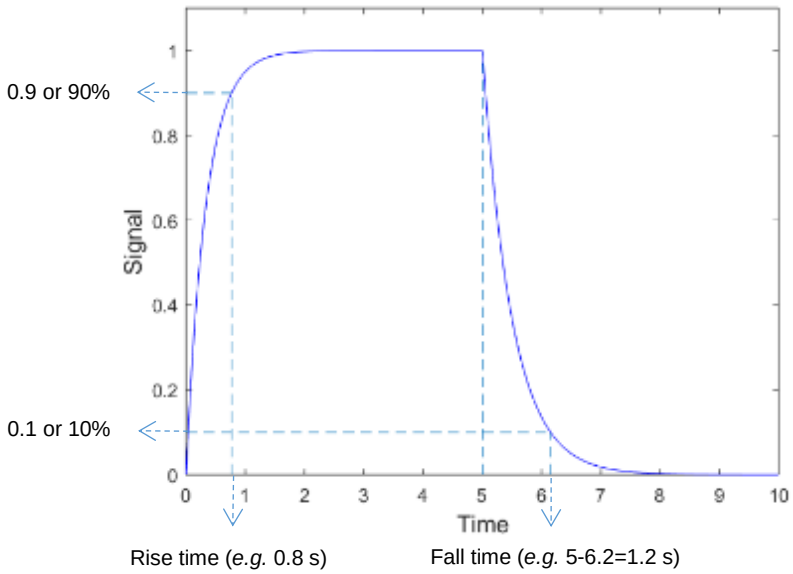

Figure 2: An example graph to illustrate the definitions of "rise time" and "fall time"

3.2.3 Key experimental parameters

The minimum key experimental parameters that should be considered and taken into account in the final test report are listed in Table 3.

Parameters	Comments
Generalities	
Test location	*Country, organization, GPS, potential accreditation, etc.*
Date	/
Labbook reference (~Test ID)	/
Operator(s) and/or custodian(s)	/
Customer	/
Test objective	/
Information about the CPD equipment or sensor	
Equipment/sensor description	*Type, serial number, technology(ies), software version, TRL (see ANNEX B), according application, data outputs, access to raw data, start up and shutdown times.*
Reference of potential previous tests	/
Equipment/sensor status	*Confidence test passed.* *Equipment/sensor calibration.* *Storage conditions (Temperature, relative humidity (RH), and storage).* *Maintenance: definition of the different maintenance realized before tests, e.g. time of last filter renewal, etc.).*
Source	
Name of substance	*Chemical name, CAS number, etc.*
Origin of substance	*Batch number, etc.*
Purity of substance	*From values of referenced or controlled analytical results.* *The substance purity of the initial substances should be determined by using at least one analytical technique.*
Impurities	*From values of referenced or controlled analytical results.*
Phase dissemination/generation method	*Gas/vapor.*
Dissemination/generation/deposition characteristics	*Flow rate, carrier gas.*
Environment	
Test facility	*Type (e.g. chamber, wind tunnel, glove box, fume hood, etc.), dimensions, layout, air filter quality, containment level, etc.*
Test conditions *(recommended to be measured if not controlled)*	*Temperature, relative humidity, wind speed.* *Temperature of the device (of the chamber).* *Temperature of the generated gas/vapor.* *Humidity of the chamber.* *Humidity of the generated gas/vapor.*
Experimental set-up	*Nose-only, total exposure, geometry, etc.* *The CPD equipment/sensor can be exposed totally to the vapor or "nose-only". Contamination aspects should be studied for a total exposition. With "nose-only" exposures, it is important to guarantee good gas/vapor sampling to enable reliable and representative test results.*
Interferents/natural or simulated background conditions	*List of interferents, concentrations, CAS, etc.*

Exposure	
Concentration Unit: [mass]/[volume] or [volume]/[volume]	*Value, stability.* *Time between measurements (recommended to be longer than fall time or clear-down time).* *Repeatability.* *Reproducibility.* *Each vapor generation method should be validated for the substances it is used for. The validation should include generation of vapor by using a specific method and gas/vapor sampling. The gas/vapor sample should be quantitatively and qualitatively analyzed and compared to the purity of the initial substance(s). List and quantities of degradation products are of most interest.* *A calibration and validation procedure should be performed to determine generated vapor concentrations.* *The stability of the vapor generation should be continuously verified with a reference system. A continuous reference system should be proven stable, precise (accurate), orthogonal or independently certified.*
Reference measurement	*Method, Name of the reference system, Frequency of measures, Stability of measures, Accuracy of measures, Calibration control (calibration certificate).*
Particle size distribution	*Not applicable for gas/vapor.*

Table 3: Recommended key experimental parameters for gas and vapor laboratory testing

3.2.4 Test materials

3.2.4.1 Threat substances: chemical warfare substances and toxic industrial compounds

Chemical warfare agents (CWA) are the substances described in the Chemical Weapons Convention of the Organization for the Prohibition of Chemical Weapons (OPCW). Warfare agents and toxic industrial compounds described in NATO AEP-72[6] Volumes 2 and 3 are recommended to be used for T&E of DIM equipment.

3.2.4.2 Simulants

As detailed in NTOP Volume I (part 3.5.2.1), simulant selection will depend on the CPD equipment and on objectives of the test being performed and which performances parameters are being characterized or investigated. In the test report, it is recommended to explain the choice of chemical compounds (simulants, and even TICs) as listed in the following Table 4 for instances.

Nota bene: for each compound (non-exhaustive list), it will be necessary to respect the safety rules (security sheets, individual and collective protection).

Technology	**Principle**	**Examples of simulants** (must be adequately sampled by the used technology)	**CAS Number**
Ion Mobility Spectrometry (IMS)	Separation of ionized molecules based on their mobility in a surrounding gas.	Dimethyl methyl phosphonate (DMMP)	[756-79-6]
		Methyl salicylate (MeS)	[119-36-8]
		Triethyl phosphate (TEP)	[78-40-0]
Flame Photometric Detector (FPD)	Formation of excited species in a flame, then spectrometric measurements of the emission processes.	DMMP	[756-79-6]
		TEP	[78-40-0]
		Dimethyl sulfoxide (DMSO)	[67-68-5]
		Sulfur dioxide (SO_2)	[7446-09-5]
		Ammonia (NH_3)	[7664-41-7]
		Acetonitrile	[75-05-8]
Infrared spectroscopy (IR)	Measurement of interaction of infrared radiation with matter (*e.g.* absorption, transmission, emission, reflection).	NH_3	[7664-41-7]
		Sulfur hexafluoride (SF_6)	[2551-62-4]
		MeS	[119-36-8]
		DMMP	[756-79-6]
		TEP	[78-40-0]

6 AEP 72/2: Chemical Agent Challenge Levels

Technology	Principle	Examples of simulants (must be adequately sampled by the used technology)	CAS Number
Raman spectroscopy or effect	Inelastic scattering process of low probability relative Rayleigh scattering used for, *e.g.*, probing energy levels of molecules.	DMMP	[756-79-6]
		Dimethyl sulfoxide (DMSO)	[67-68-5]
		MeS	[119-36-8]
Colorimetric detection	Presence of target C substances indicated by chemical and/or acid-base reactions resulting in a color change.	To be chosen according to the specific reaction with the colorimetric process.	/
Electrochemical cells (EC)	Gas reacting with sensing/working electrode(s) (specific of gas of interest) and with a counter electrode separated by an electrolyte, which produces an electrical current related to gas concentration.	NH_3	[7664-41-7]
		SF_6	[2551-62-4]
Surface acoustic waves (SAW)	Piezoelectric crystals detecting mass of C vapors absorbed into chemically selective coatings on sensor surface. This absorption causes a change in the resonant frequency used to determine the presence and concentration of C substances.	DMMP	[756-79-6]
		MeS	[119-36-8]
Gas Chromatography / mass spectrometry (GC / MS)	GC separates the constituent of gaseous mixture by using their specific retention time in a stationary phase in a column. MS (single or after the GC step) measures the mass to charge ratio of ions of each constituent previously separated and ionized by subjecting the constituents to a bombardment of electrons. MS spectrum is obtained both to quantify and either to elucidate the chemical structure for identify with reference databases.	Simulant kits (*e.g.* mixture of C compounds with sufficient vapor pressure)	/
Photo-or Flame-ionization Detector (PID or FID)	Photo-ionization (PID) or combustion by mean of flame (FID) of a gas/vapor in a carrier gas (usually air), and then detection by measuring the generated charged atoms or molecules.	All compound that can be ionized (enough energy)	/
Biochemical sensors	For chemical compound, device capable of converting a chemical quantity into an electrical signal"	Specific according to the reactivity of the sensor.	/

Table 4: Non-exhaustive examples for chemical compounds (simulants, TICs, *etc*.) according to some examples of technologies used by the CPD equipment

3.2.4.3 Interferents

Some standard backgrounds (rural, urban, industrial, *etc*.) are recommended to be used. Even if standards are not easy to define, this would ease the ability to compare and share the evaluation results of CPD systems between different nations. It is recommended to detail and report the composition of background used for tests (concentration of each interferent). For instance, if mean compositions of backgrounds representative of rural, urban or industrial areas are known, such mixtures can become standard. It is also recommended to use common interferents such as petrol, oil,

engine exhaust, smoke, lubricants (POL), decontaminants, and any other relevant substances that can be generated in lab environments.

3.2.5 Examples of experiments

Examples of experiments are suggested in ANNEX C.

3.2.6 Test report

In the test report, recommended experimental parameters and materials that have been used should be clearly described. The test results, their interpretation and the conclusions, *i.e.*, the evaluation of the key parameters should be included. The measured raw data and metadata, set parameters need to be documented and accompany the test results for proper intra- and inter-laboratories comparisons. Test forms (ANNEX C) can be used as template, in order to harmonize as much as possible the test execution and reporting between different nations.

3.3 LIQUID / SOLID (BULK SUBSTANCE)

Liquid and/or solid matter in bulk refers to substance matter with a quantity that can be seen, touched or weighed by an operator (at normal conditions of temperature and pressure). This paragraph will be addressed in future versions of this Volume II.

3.4 SURFACE CONTAMINATION

Surface contamination refers to scenarios where C substance is deposited onto various surfaces on personnel, equipment, vehicles, *etc*. or ground after an exposure (reconnaissance, decontamination validation, *etc.*). This paragraph will be detailed later in future versions of this Volume II. For information, an annex on DIM of C surface contamination will be written in the projected STANREC AEP-4835 Capability and system requirements for CB DIM equipment.

3.5 AEROSOLS

C substances may be dispersed as aerosols which are liquid or solid particles in a gas (generally air). This paragraph will be addressed in future versions of this Volume II.

CHAPTER 4 TEST APPROACH 2 – FIELD TESTING

4.1 PURPOSE OF EVALUATION

1. The objective of field testing is to evaluate the performance of CPD equipment when detecting C substances under more representative/realistic environmental conditions than the controlled ones of laboratory testing.

2. Each field testing range used for the T&E of CPD equipment presents some realistic conditions. Obviously, these conditions are not exhaustive and limited, which partially cover only some possible operational circumstances. Yet, the benefit of field testing remains important because simulants and in some cases also live agents can be used safely if authorized, which is not possible in operational environments because of *e.g*. costs and environmental, health and safety regulations and risks.

3. Evaluation is typically performed when the CPD equipment has an established alarm algorithm (see CPD equipment evaluation in part 3.2 of Laboratory testing).

4.2 GAS AND VAPOR

4.2.1 Minimum key parameters

Table 5 presents the different parameters that could be evaluated in field-testing.

Parameters	Details
Sensitivity: minimal detectable substance quantity.	**Alarm level**: concentration level at which the CPD equipment alarms.
Response time: time needed for the CPD equipment to react. Also time for the system to refresh the information[7].	**Time-to-alarm**: time from exposure at a concentration level corresponding to the alarm level until the CPD equipment triggers an alarm.
	Clear-down time: time from end of exposure at a concentration level corresponding to the alarm level until the CDP equipment turns of the alarm.
Selectivity: ability of the CPD system of differentiating in the presence of other components.	**False alarm rate FAR**: rate at which the CPD equipment can be expected to trigger false alarms (*e.g.* 1/day, 1/week, 1/year).
	Detection probability P_D: probability that the CPD equipment will trigger an alarm when the C substance is present at a concentration level corresponding to the alarm level.

Table 5: Recommended minimum key parameters for gas and vapor field-testing

4.2.2 Test materials

4.2.2.1 Threat substances

See part 3.2.4.1.

7 Chemical and Biological Warfare Agents (CBWA) Early Warning and Detection Triptych, D/100 (reference document) edition 5, 2011. This D document will be integrated in the future STANREC AEP-4835 on NATO Capability and System Requirements for CB DIM Equipment (in process).

4.2.2.2 Simulants

See part 3.2.4.2.

4.2.2.3 Interferents / Natural interferents

1. A plus value of field-testing compared to laboratory is that the influence of weather conditions (temperature, relative humidity, wind speed and direction) can be evaluated. Because field-testing is realized outdoors, interferents cannot be controlled. The presence of interferents and their concentration should be then monitored in order to be able to interpret results. Like in laboratory, usual battlefield interferents (*e.g.* smoke of weapons, *etc*.) could be also artificially produced and generated. Smokes and interferents from decontamination solutions should be evaluated.

2. With field-testing, the levels of interferences are going to be different depending on the environment. If there is a standard chart that allows each test to record their background, it is then recommended to give detail on minimal and maximal parts per million (ppm) per contaminant for each environment to standardize testing key experimental parameters

4.2.3 Key experimental parameters

Table 6 details the key experimental parameters to be considered and taken into account in the final report.

Parameters	Comments
Generalities	
Test location	*Country, organization, GPS, potential accreditation, etc.*
Date	/
Labbook reference (~Test ID)	/
Operator(s) and/or custodian(s)	/
Customer	/
Test objective	/
Information about the CPD equipment	
Equipment description	*Type, serial number, technology(ies), software version, TRL (see annex B), data outputs, access to raw data, start up and shutdown times.*
Reference of potential previous tests	/
Equipment status	*Confidence test passed.* *Equipment calibration.* *Storage conditions (Temperature, RH, and storage).* *Maintenance: definition of the different maintenance realized before tests (e.g. time of last filter renewal, etc.).*
Source	
Name of substance	*Chemical name, CAS Number, etc.*
Origin of substance	*Batch Number, etc.*
Purity of substance	*From values of referenced or controlled analytical results.* *The substance purity of the initial agents should be determined by using at least one analytical technique.*
Impurities	*From values of referenced or controlled analytical results.*
Phase dissemination/generation method	*Gas/vapor.*
Environment	
Test conditions	*Weather conditions: temperature, humidity and wind conditions (speed and direction).*
Experimental set-up	*Configurations of the test place, etc.*
Interferents/natural conditions	*List of monitored interferents, concentrations, etc.*
Exposure	
Concentration Unit: [mass]/[volume] or [volume]/[volume]	*Value, stability.* *Time between measurements (recommended to be longer than fall time or clear-down time).* *Repeatability.* *Reproducibility.*
Reference measurement	*Method, Name of the reference system, Frequency of measures, Stability of measures, Accuracy of measures, Calibration control (calibration certificate).*
Particle size distribution	*Not applicable for gas/vapor.*

Table 6: recommended key experimental parameters for gas and vapor field-testing

4.2.4 Generalities on experimental methods for field testing

1. Contrary to laboratory testing, the ambient conditions are obviously more random and difficult to control. If possible, it is so recommended to use a metrology to characterize these conditions like meteorological measurements during the field trials for instance. The knowledge of the topography of the location can also be useful.

2. If possible, the measurement of the quantity of C substance released should be done by one or several reference DIM systems (*e.g.* network of point and/or standoff and/or remote DIM system).

4.2.5 Examples of experiments

Examples of recommended experiments are proposed in ANNEX D.

4.2.6 Test report

In the test report, it is recommended to describe the key experimental parameters (see Table 6) and materials that have been used (see part 4.2.2). The experimental results, their interpretation and the conclusions aim at leading to the evaluation of the key sensor/system parameters (see part 4.2.1). Test forms (ANNEX D) can be used as template, in order to ease the reading by different nations.

4.3 LIQUID / SOLID (BULK SUBSTANCE)

This paragraph will be detailed later in future versions of this Volume II.

4.4 SURFACE CONTAMINATION

This paragraph will be detailed later in future versions of this Volume II.

4.5 AEROSOLS

This paragraph will be detailed later in future versions of this Volume II.

CHAPTER 5 TEST APPROACH 3 –OPERATIONAL TESTING

5.1 PURPOSE OF EVALUATION

Operational Testing consists of testing the sensors within military environments and scenarios. It is designed to evaluate the effectiveness and suitability of the system with respect to its intended use. The testing is performed either by the end user or by a dedicated operational team. Operational testing can be performed on:

a. prototypes;

b. first mass-produced equipment or COTS.

Operational testing of prototypes is an early involvement of the users in a test process that can give valuable information for its further development. Operational testing on first mass-produced or COTS equipment is usually conducted in order to confirm the system fulfilment of the military requirements in real conditions, and to verify the reliability of equipment.

5.2 GAS AND VAPOR

5.2.1 Recommended key operational parameters

Table 7 shows the different suggested operational parameters that could be evaluated during operational testing (DOTMLPFI approach for a military capability).

Parameters
Doctrine - Organization
Training
Material: Maintenance system - Logistics system
Leadership
Personnel
Facilities - Infrastructure
Interoperability - Rules and Limits of employments

Table 7: recommended key operational parameters

5.2.1.1 Doctrine – organization and concept of employment

1. The evaluation should be assessed if national and NATO doctrines properly describe the military capabilities that will operate the CPD equipment. The evaluation aims also at determining if these doctrines have to be updated.

2. The evaluation aims at assessing if the delivery of the equipment under test to the end users will have an impact on their organizations (*e.g.* will they have to adapt the description of their manpower to take into account the CPD equipment? Will they need to create new platoons to operate the equipment?).

3. The military capabilities of the equipment are then described. The employment of the DIM system is then stated for the unit's SOP.

4. New technology employment concept will usually come from the manufacturer, as it has been designed in such a way that the concept of operations has already been decided.

5.2.1.2 Training

The team conducting operational testing should assess the ability to train the users, not only for the very first testing process but also for a sustainable use by the end users during all the lifecycle of the equipment. This assessment should include the training of people in charge of the maintenance of the equipment, when it is not outsourced to private companies.

5.2.1.3 Material: Maintenance system and Logistics system

a. Maintenance system

The sustainability of the maintenance concept should be evaluated (*e.g.* can you supply spare parts on the field? Can you repair or outsource the maintenance of the equipment when deployed on operations? If the maintenance is different when the equipment is not deployed on operation, is it sustainable also?).

b. Logistics system

Concerning the logistics system, the following items should be evaluated:

(1) ability to deliver the equipment to troops on the field with usual operational means of transportations (*e.g.* warfare vessels, tactical aircraft, army transport trucks, *etc.*),

(2) ability to deliver the logistic requirements of maintaining and sustaining the equipment,

(3) security constraints for transportation of both the equipment and all of the consumables required to operate it, while transporting them by road, train, sea or air (IATA DGR[8], RID[9] constraints, *etc*.).

5.2.1.4 Facilities - Infrastructure

Operational testing should assess the need to develop specific infrastructure either for the training to the use of the equipment, and for its maintenance (including the training for the maintenance of the equipment).

8 International Air Transport Association Dangerous Goods Regulations
9 Regulations concerning the International carriage of Dangerous goods by rail

5.2.1.5 Personnel, Interoperability, Rules and Limits of employments

1. The following and non-exhaustive list of topics should be evaluated:

   a. number of user(s) to operate the CPD equipment and their minimum level of training,

   b. ability to wear usual CBRN IPE (Individual Protective Equipment) while carrying and operating the equipment,

   c. ability to embark the equipment in vehicles[10], ability to operate the equipment while conducting a mission in the vehicle, ability to operate CBRN COLPRO (collective protection) while embarking and/or operating the equipment, operability on UAV's and UGV's[11]

   d. ability to use individual or collective weapon while carrying/operating the equipment,

   e. ability to conduct night missions with the equipment (*i.e.* concealment) and to use night vision goggles (NVG) while operating the equipment,

   f. monitoring of weather and temperature values during the evaluation. Extreme weather and temperature limits of use of the equipment should be investigated (*i.e.* conduct evaluation in harsh terrain, jungle, desert, *etc*.). Due to the difficulties to control temperature on field tests, environmental chambers in laboratories could be used (for instance to control extreme temperatures or T&E: -30 to +40°C),

   g. ability to conduct operational and thorough decontamination of the equipment when using usual decontamination equipment and procedures.

2. Interoperability consideration can occur when a DIM equipment is employed by another NATO country at this time.

5.2.2 Test materials

5.2.2.1 Threat substances

See part 3.2.4.1.

5.2.2.2 Simulants

See part 3.2.4.2.

10 *I.e.* APC (armored personnel carrier), tanks, reconnaissance vehicles, *etc*.
11 UAV = unmanned airborne vehicle; UGV = unmanned ground vehicle.

5.2.2.3 Artificial and natural interferents

In order to conduct realistic operational testing, it is recommended to evaluate the equipment in an environment with usual battlefield interferents that can be produced. For example, these interferents could be C substances like tear gases (CS grenades, *etc*.), masking or exhaust fumes, combustion products or residues (*e.g.* smokes from various origins such as gunfire, artillery shells, smoke grenades, vehicles wrecks tires, usual POL, *etc*.). Interferents from decontamination solutions should be evaluated. The details of the production of artificial interferents should be recorded for further investigation of the results of the evaluation.

5.2.3 Key experimental parameters

Table 8 lists the key experimental parameters to be taken into account, and reported in the final report.

Parameters	Comments
Generalities	
Test location	*Country, organization, GPS, potential accreditation, etc.*
Date	/
Lab book reference (~Test ID)	/
Operator(s) and/or custodian(s)	/
Customer	/
Test objective	/
Information about the CPD equipment	
Equipment description	*Type, serial number, technology(ies), software version, TRL (see ANNEX B), data outputs, access to raw data, start up and shutdown times.*
Reference of potential previous tests	/
Equipment status	*Confidence test passed.* *Equipment calibration.* *Storage conditions (Temperature, RH, and storage).* *Maintenance: definition of the different maintenance realized before tests (e.g. time of last filter renewal, etc.).*
Source	
Name of substance	*Chemical name, CAS number, etc.*
Origin of substance	*Batch number, etc.*
Purity of substance	*From values of referenced or controlled analytical results.* *The substance purity of the initial substances should be determined by using at least one analytical technique.*
Impurities	*From values of referenced or controlled analytical results.*
Phase dissemination/generation method	*Gas/vapor.*
Environment	
Test conditions	*Weather conditions: temperature, humidity and wind conditions (speed and direction).*
Experimental set-up	*Configurations of the test place, etc.*
Interferents/natural conditions	*List of monitored interferents, concentrations, etc.*
Exposure	
Concentration Unit: [mass]/[volume] or [volume]/[volume]	*Value, stability.* *Time between measurement (It is recommended that this time be longer than fall time or clear-down time).* *Repeatability.* *Reproducibility.*
Reference measurement	*Method, Name of the reference system, Frequency of measures, Stability of measures, Accuracy of measures, Calibration control (calibration certificate).*
Particle size distribution	*Not applicable for gas/vapor.*

Table 8: recommended key experimental parameters for gas and vapor operational testing

5.2.4 Examples of experiments

Recommended experiments are suggested in ANNEX E.

5.2.5 Test report

In the test report, it is recommended to describe the key experimental parameters (see Table 8) and materials that have been used (part 5.2.2). The experimental results, their interpretation and the conclusions aim at leading to the evaluation of the operational parameters (see Table 7). Test forms (ANNEX E) can be used as template, in order to ease the reading by different nations.

5.3 LIQUID / SOLID (BULK SUBSTANCE)

This paragraph will be detailed later in future versions of this Volume II.

5.4 SURFACE CONTAMINATION

This paragraph will be detailed later in future versions of this Volume II.

5.5 AEROSOLS

This paragraph will be detailed later in future versions of this Volume II.

CHAPTER 6 COMPLEMENTARY TOOLS – SIMULATION AND MODELING

During each stage of their development and associated TRL, a CPD system can be modeled and simulated by means of various tools. Some models are suggested in ANNEX F for gas and vapor. The modeling and simulation (M&S) tools can be based on experimental data to get more data by avoiding realizing some real trials that can be consuming in terms of human and material resources, time, money and complex environmental regulations.

ANNEX A GLOSSARY AND DEFINITIONS

A 1. GLOSSARY

AEP	Allied Engineering Publication
ATP	Allied Tactical Publication
CBRN	Chemical, Biological, Radiological and Nuclear
COTS	Commercial Off The Shelf
CPD	Chemical Point Detection, identification and monitoring
CW	Chemical Warfare
CWA	Chemical Warfare Agent
DIM	Detection, Identification and Monitoring
DOTMLPFI	Doctrine, organization, training, materiel, leadership development, personnel, facilities and interoperability
GC-FID	Gas Chromatography – Flame Ionization Detection
GC-FPD	Gas Chromatography – Flame Photometry Detection
GC-MS	Gas Chromatography – Mass Spectrometry
IMS	Ion Mobility Spectrometry
IPE	Individual Protective Equipment
IR	Infrared
ISO	International Organization for Standardization
LOD	Limit of Detection
M&S	Modeling and Simulation
NAAG	NATO Army Armament Group
NATO	North Atlantic Treaty Organization
NTOP	NATO Test and evaluation Operating Procedure
OPCW	Organization for the Prohibition of Chemical Weapons
P_D	Detection probability
P_{FN}	False negative probability
P_{FP}	False positive probability
POL	Petroleum, oils and lubricants
R&D	Research and Development
RH	Relative Humidity
ROC	Receiver Operating Characteristic
SAW	Surface Acoustic Waves
SOP	Standard Operating Procedure
T&E	Test & Evaluation
TIC	Toxic Industrial Chemical
TRL	Technology Readiness Level

A 2. NATO DEFINITIONS

The following definitions mainly come from the NATO Standardization Office (NSO) and the definitions of the terms used by NATO (called “NATOTerm”). They are available on NSO website https://nso.nato.int. For the other definitions, the sources are mentioned.

Active	In surveillance, an adjective applied to actions or equipment that emit energy capable of being detected. (AAP-06:2019[12])
CBRN substance	A toxic chemical or harmful biological substance, a toxic industrial material or a radioactive material, in any physical state or form.
Detection	In chemical, biological, radiological and nuclear defense, the discovery, by any means, of the presence of a chemical, biological, radiological and nuclear substance.
DOTMLPFI	Doctrine, organization, training, materiel, leadership development, personnel, facilities and interoperability.
Evaluation	The structured process of examining activities, capabilities and performance against defined standards or criteria. Note: In the context of military forces, the hierarchical relationship in logical sequence is assessment, analysis, evaluation, validation and certification. (AAP-06)
Identification	Determination of the presence of a specific CBRN substance. The process of attaining an accurate characterization of a detected entity by any act or means so that high confidence real-time decisions, including weapons engagement, can be made. (AAP-06)
Point detector	Point detectors react to hazards at the point of interception. (ATP 3.8.1 vol. 1)
POL	Petroleum, oils and lubricants
Validation	The confirmation of the capabilities and performance of organizations, individuals, materiel or systems to meet defined standards or criteria, through the provision of objective evidence.(AAP-06) Note: in the context of military forces, the hierarchical relationship in logical sequence is assessment, analysis, evaluation, validation and certification.

[12] AAP-6:2019: NATO Glossary of Terms and Definitions (English and French)

A 3. TECHNICAL DEFINITIONS

Aerosol	System of solid or liquid particles suspended in gas. [ISO 15900:2020: Determination of particle size distribution - Differential electrical mobility analysis for aerosol particles]. The gaseous medium is usually some air.
Alarm	Audible and visual signal alerting a condition requiring immediate attention or user action. [ISO 8468:2007: Ships and marine technology -- Ship's bridge layout and associated equipment -- Requirements and guidelines]. In a CBRN context, it is an indication from any source that a CBRN attack or release other than attack may have occurred.
Clear-down time	Time taken for the equipment under test to turn off the alarm after being exposed to uncontaminated environment again.
False alarm	Anomaly of the system leading to an unjustified warning or alarm. [ISO 21750:2006: Road vehicles Safety enhancement in conjunction with tyre inflation pressure monitoring]
Limit of detection (LOD)	The International Organization for Standardization, ISO defines the LOD as the true net concentration (or quantity) of component in the material subject to analysis that will lead with a probability to conclude that the concentration (or quantity) of component in the material analyzed is greater than that of a blank sample. [ISO 11843-1:1997. Capability of detection. Part 1: Terms and definitions.] and [IUPAC. Nomenclature in Evaluation of Analytical Methods including Detection and Quantification Capabilities, Pure & Appl. Chem., 67, 1699–1723 (1995)] The International Union of Pure and Applied Chemistry, (IUPAC) in an earlier document, provided a similar definition and adopted the term "minimum detectable (true) value", as the equivalent to LOD. https://goldbook.iupac.org/terms/view/L03540
Precision	The closeness of agreement between independent test results obtained under stipulated conditions. [ISO 3534-1: Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability]
Repeatability	Precision under repeatability conditions. [ISO 3534-1: see above]
Repeatability conditions	Conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time [ISO 3534-1: see above]
Reproducibility	Precision under reproducibility conditions. [ISO 3534-1: see above]
Reproducibility conditions	Conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment. [ISO 3534-1: see above]
Response (of a system)	Output quantity of a system. [ISO 2041:2018: Mechanical vibration, shock and condition monitoring - Vocabulary]
Response time	Time needed for the system (in a wide sense, including hardware and software) to take a decision. It can also be seen as the time for the system to refresh the information. (see D/100 ed. 5 – Annex C or future STANREC AEP-4835)

Selectivity and specificity	"Selectivity" refers to the extent to which a method can determine particular substances (or analytes) in mixtures or matrices without interferences from other components. Selectivity is the recommended term in analytical chemistry to express the extent of interferences. To avoid confusion, the use of the term "specificity" is to be discouraged; IUPAC (International Union of Pure and Applied Chemistry) has stated that "specificity" is the ultimate stage of "selectivity". IUPAC has mentioned that the term "specificity" suggests that no component other than the analyte contributes to the result. Because hardly any method is specific in general, the term should be avoided". [Pure Appl. Chem., Vol.73, No.8, pp.1381–1386, 2001, IUPAC Recommendations 2001)
Sensitivity	Generally defined by the minimal detectable substance quantity. However, there can be some debate in defining "sensitivity". In "Point on the meaning of sensitivity", Ekins *et al*., Clin. Chem., Vol. 43, Is. 10, Oct. 1997, Pp. 1824–1831: certain authorities (*e.g*. IUPAC) define a system's sensitivity as the response curve slope (or response/dose), others (*e.g.* IFCC) in terms of the detection limit.
Start-up time	Start-up time is the time between when the sensor is turned on and when the sensor is ready to give a reliable answer.
Shut-down time	Shut-down time is the time for the sensor to shut down after the operator turned it off.
Time-to-alarm	Time from exposure of the substance at a concentration above the alarm limit until an alarm from the system is recorded.
Verification	Examination to confirm that an activity, a product or a service is in accordance with specified requirements. [ISO 13628-7:2009: Petroleum and natural gas industries — Design and operation of subsea production systems — Part 7: Completion/workover riser systems]

ANNEX B TECHNOLOGY READINESS LEVELS (TRL)

Source: page 848-849 of Defense Acquisition Guidebook (16 Sept. 2013, https://www.dote.osd.mil/Portals/97/docs/TEMPGuide/DefenseAcquisitionGuidebook.pdf).

Technology Readiness Level		Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system are tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7	System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

ANNEX C EXAMPLES OF EXPERIMENTS FOR GAS/VAPOR LABORATORY TESTING

C.1 Some key sensor/detector parameters are strongly linked. Therefore some experiments can be realized to test and evaluate different sensor/detector parameters in the same time, by taking into account the previous detailed key evaluation parameters. Examples of recommended experiments are summarized in three kinds of T&E forms. These T&E forms are structured in six parts:

1. purpose of the experiment;
2. general description of the experiment;
3. measurement during the experiment;
4. applicable documents;
5. key experimental parameters;
6. experiment constraints.

C.2 These T&E forms can be used as test plans or test reports. For each type of experiment described in a certain form, Table 9 shows which key parameters are evaluated in each T&E form.

Parameters	Form n°1	Form n°2	Form n°3
Sensitivity: LOD or Alarm level	x		
Response time: rise time or time-to-alarm	x		
Response time: fall time or clear-down time	(x)		x
Selectivity / False negative probability	x (1c)		
Selectivity / False negative probability	x (1a, 1b)		
Selectivity / False positive probability	x (1c)		
Selectivity / False positive probability		x	

Table 9: Summary of T&E forms

a. Form n°1

According to the level of T&E we want to process, Form n°1 is divided into the three following parts:

(1) Form n°1a describes basic T&E (in blue);

(2) Forms n°1b and 1c describe advanced T&E (in orange), leading to ROC curves establishment.

For Form n°1, two kinds of CPD equipment are studied: warning (quick alarm) and monitoring (continuous acquisition). Form n°1a describes experiment used preferentially to verify some specifications. It is then primarily dedicated to detector evaluation. Since Form n°1b conducts to the establishment of ROC curve without access to raw data, it is primarily dedicated to detector evaluation. Since Form n°1c

conduct to the establishment of ROC curve with access to raw data, it is primarily dedicated to sensor evaluation.

Chemical gas/vapor Point Detection Laboratory Testing	**Form n°1a**
Sensitivity (Alarm level) **+ Selectivity (False negative probability P_{FN} or detection probability P_D)** **+ Time-to-alarm** ***(+ Clear-down time)***	***Basic T&E*** ***(primarily dedicated to detector evaluation)***

1 - PURPOSE

Case A: Warning (detector alarm response). The following purposes are to determine or verify:

- the capability of the CPD equipment to give an alarm in a specified time (rise time or time-to-alarm), at a specified gas/vapor concentration in these following conditions with:
  - clean air,
  - specific backgrounds / interferents.
- the selectivity (false negative probability P_{FN} or detection probability P_D) in the above conditions,
- (fall time or clear-down time after the exposure.)

Case B: Monitoring (detector signal response). The following purposes are to determine or verify:

- the rise time or time-to-alarm to give the first alarm,
- the capability of the equipment to give and maintain the alarm during a specific time at a specific gas/vapor concentration (LOD or alarm level) in the following conditions with:
  - clean air;
  - specified backgrounds / interferents.
- the selectivity (false negative probability P_{FN} or detection probability P_D) in the above conditions,
- (determine or verify fall time or clear-down time after the exposure.)

2 - GENERAL DESCRIPTION OF THE EXPERIMENT

Static or dynamic generation of substance gas/vapor at the lowest concentration that equipment can detect (LOD or Alarm level).

To achieve the desired concentration, dilutions should be made with:

- clean air,
- specific backgrounds / interferents representatives of rural, urban or industrial areas, (smokes), *etc.* The composition should be known in details in the test report.

The equipment is exposed to contaminated atmosphere depending on the case (A or B). The equipment answer to the different gas/vapor is verified and recorded if possible.

Nota bene: it is recommended to do some “blank” with the equipment in order to check that it is “clean” enough between data collection points.

Case A (Warning):

Gas/vapor exposure repetitions (X times) must be adapted to the selectivity we want to evaluate (defined by the user, for instance at 0.1% if unknown).

Gas/vapor exposure time must be adapted to the response time and to the need (operational need or other). Between successive gas/vapor exposures, the equipment should be subjected to clean air during a longer time than the fall time or clear-down time.

Case B (Monitoring):

The exposure time should be adapted in order to be able to achieve the P_{FN} (defined by the user, for instance at 0.1% if unknown): response time and information refreshment time have to be taken into account in order to obtain required enough information. In other words, the number of measured values at each concentration should be large enough to achieve a desired confidence limit.

Alarm inhibition is automatic or manual according to the CPD equipment.

3 - MEASUREMENT
Case A (Warning): The time-to-alarm is measured. During the X gas/vapor exposure repetitions, P_{FN} is calculated. *(After each exposure, fall time or clear-down time is measured.)* Case B (Monitoring): The time-to-alarm is measured. During the exposure time, P_{FN} is calculated (see definition part 3.2). *(After each exposure, fall time or clear-down time is measured.)*
4 - APPLICABLE DOCUMENTS
• User's manuals. • National SOP (standard operating procedures).
5 – KEY EXPERIMENTAL PARAMETERS
See Table 3 (part 3.2.3).
6 - EXPERIMENTAL CONSTRAINTS
• Size and weight of the CPD equipment. • In case of a dynamic generation, the contaminated flow must be higher than the sampling flow of the equipment. • Interface between the test rig and the equipment.

Chemical gas/vapor Point Detection Laboratory Testing	Form n°1b
Alarm level + Selectivity / False negative probability P_{FN} + Time-to-alarm *(+ Clear-down time)* *ROC curve without access to raw data*	***Advanced T&E (primarily dedicated to detector evaluation)***

1 - PURPOSE

Case A: Warning (quick alarm)

Thanks to experimental measurements, the purpose is to establish the ROC Curve represented by "Concentration = function(false negative probability)", for a specific time (time-to-alarm), in these following conditions with clean air AND/OR specified backgrounds / interferents.

(+ determination or verification of the clear-down time after the exposure.)

Case B: Monitoring (continuous acquisition)

Thanks to experimental measurements, the purpose is to establish the ROC Curve represented by "Concentration = function(false negative alarm probability)", during a specific time, in these following conditions with clean air AND/OR specified backgrounds / interferents.

(+ determination or verification of the clear-down time after the exposure.)

2 - GENERAL DESCRIPTION OF THE EXPERIMENT

Static or dynamic generations of substance gas/vapor at different concentrations.

Four TIC or CWA concentrations are generated (C1 to C4, with C1<C2<C3<C4, the range between C1 and C4 is depending on the CPD equipment). If the manufacturer defines an alarm level, then this level = C2. If not, C2 is the recommended value in D/100 or future STANREC AEP-4835.

To achieve the desired concentration, dilutions should be made with:

- clean air;
- specified backgrounds / interferents representatives of rural, urban or industrial areas, (smokes), *etc.* The composition should be known in details in the test report.

The CPD equipment is exposed to contaminated atmosphere depending on the case (A or B). The equipment answer to the different gas/vapor is verified and recorded if possible.

Case A (Warning):

For each concentration, the exposure is repeated X times, X must be adapted to a target P_{FN}. Exposure time must be adapted to the time-to-alarm. After an exposure, the equipment should sample clean air longer than the clear-down time.

(After each exposure, clear-down time is measured.)

Case B (Monitoring):

For each concentration, exposure time is adapted in order to be able to achieve a target P_{FN}: time-to-alarm and information refreshment time have to be taken into account in order to have enough information.

(After each exposure, clear-down time is measured.)

3 - MEASUREMENT

Case A (Warning):

For each concentration, on the X repetitions, P_{FN} is calculated. Thanks to all the evaluated concentrations, the graph Concentration = f(P_{FN}) is drawn.

Case B (Monitoring):

For each concentration, the response time necessary to trigger off the first alarm is measured.

During the exposure time, P_{FN} is calculated. For each concentration, a couple (Concentration, P_{FN}) is then defined.

Thanks to all the evaluated concentrations, the graph Concentration = f(P_{FN}) is drawn.

4 - APPLICABLE DOCUMENTS

- User's manuals, national SOP.

5 – KEY EXPERIMENTAL PARAMETERS

See Table 3 (see part 3.2.3).

6 - EXPERIMENTAL CONSTRAINTS

- Size and weight of the CPD equipment.
- In case of a dynamic generation, the contaminated flow must be higher than the sampling flow of the equipment.
- Interface between the test rig and the equipment.

Chemical gas/vapor Point Detection Laboratory Testing	Form n°1c
Limit of detection (LOD) **+ Selectivity / False negative probability P_{FN} and false positive probability P_{FP}** **+ Rise time** ***(+ Fall time)*** ***ROC curve with access to raw data***	***Advanced T&E*** ***(primarily dedicated to sensor evaluation)***

1 - PURPOSE

The following purposes are:

- to evaluate the rise time (by experimental means or by calculation thanks to raw data),
- to establish ROC curves thanks to an adapted software and program.

For ROC Curve explanation: see D/100 ed. 5 - Annex C (or future STANREC AEP-4835).

ROC curves are established for a specific rise time and a specific background / interferent.

Different graphs can be drawn:

Case 1: "Concentration = function (False positive probability or P_{FP})", with fixed false negative probability.

Case 2: "Concentration = function (False negative probability or P_{FN})", with fixed false positive probability.

This ROC curve is equivalent to the one described in Form n°1b, but the one in this Form is established thanks to a data soft treatment.

Case 3: For a specific concentration of substance, the ROC curve is "Detection probability = function (False positive probability P_{FP})", with Detection probability P_D = 1 – False negative probability P_{FN}.

2 - GENERAL DESCRIPTION OF THE EXPERIMENT

Data acquisition from the exposure to a specific background:

The equipment under test should be exposed to:

- clean air;
- specific backgrounds / interferents representatives of rural, urban or industrial areas, (smokes), *etc*. The composition should be known in details in the test report.

Exposure time to a specific condition is at least 8 hours.

Raw data are recorded.

Data acquisition from the exposure to a contaminated atmosphere (CWA or TIC):

Static or dynamic generation of TICs or CWAs vapors at different concentrations.

Four TIC or CWA concentrations are generated (C1 to C4, with C1<C2<C3<C4, the range between C1 and C4 is depending on the equipment). If the manufacturer defines a LOD, then LOD = C2. If not, C2 is the D/100 (or future STANREC AEP-4835) value.

To achieve the desired concentration, dilutions are made with clean air only.

For each concentration, exposure time is adapted in order to be able to achieve enough data.

Raw data are recorded.

3 - MEASUREMENT

Data are processed thanks to specific software and program. Each Nations can use its own development. The most important item is to choose in recorded data the best descriptor(s) (*e.g.* signal from an atomic ray, linear combination from different specific rays, *etc.*). Then for the selected descriptor, statistical distributions are defined for each concentration of substances and each specific background.

These statistical distributions will be processed to draw the wanted ROC curves according to the case (1, 2 or 3) → for further explanations, see D/100 ed. 5 - Annex C (or future STANREC AEP-4835).

4 - APPLICABLE DOCUMENTS

- User's manuals.
- National SOP.

5 – KEY EXPERIMENTAL PARAMETERS

See Table 3.

6 - EXPERIMENTAL CONSTRAINTS

- Size and weight of the equipment under test.
- In case of a dynamic generation, the contaminated flow must be higher than the sampling flow of the equipment.
- Interface between the test rig and the equipment.

b. Form n°2

Form n°2 is primarily dedicated to CPD (like detector) evaluation (no ROC curves).

Chemical gas/vapor Point Detection Laboratory Testing	**Form n°2**
Selectivity / False positive probability P_{FP}	***Basic T&E*** ***(primarily dedicated to detector evaluation)***
1 - PURPOSE	
The purpose is to determine or verify the False Positive Probability P_{FP} evaluated without any substance gas/vapor present in these following conditions with: • clean air; • specific backgrounds / interferents.	
2 - GENERAL DESCRIPTION OF THE EXPERIMENT	
The CPD equipment is tested without any TIC or CWA in these following conditions with: • clean air, for instance in the lab or outside by ensuring that there is no obvious pollution; • specific backgrounds /interferents representatives of rural, urban or industrial areas, (smokes), *etc.* The composition should be known in details in the test report. Exposure time must be adapted to the P_{FP} we want to achieve (defined by the user, for instance at 0.1% if unknown). Exposure time should not exceed 8 hours. The CPD equipment answer is verified and recorded if possible.	
3 - MEASUREMENT	
During the test under specified conditions, the equipment will have taken N decisions. False positive alarms (FA) are counted (either by looking at the equipment during the test, or by using the soft data). The P_{FP} is defined as the quotient FA/N.	
4 - APPLICABLE DOCUMENTS	
• User's manuals. • National SOP.	
5 – KEY EXPERIMENTAL PARAMATERS	
See Table 3 (see part 3.2.3).	
6 - EXPERIMENTAL CONSTRAINTS	
• Size and weight of the equipment. • In case of dynamic generation for background or interferents, this flow must be higher than the sampling flow of the equipment. • Interface between the test rig and the equipment.	

c. Form n°3

Form n°3 can be applied either for sensor or system (like detector) evaluation.

Chemical gas/vapor Point Detection Laboratory Testing	Form n°3
Fall-time or clear-down time	***Basic T&E***
1 - PURPOSE	
After an exposure to a contaminated atmosphere (CWA or TIC) and once the equipment is outside this contaminated atmosphere, the purpose is to determine or verify the fall-time or the clear-down time. Experiments could be done through Form n°1 (and n°4).	
2 - GENERAL DESCRIPTION OF THE EXPERIMENT	
The equipment has to be exposed to a contaminated atmosphere (CWA or TIC), in which the concentration is at least the specified LOD or alarm level (see Form n°1). When the equipment is removed from the contaminated atmosphere clear-down time (detector evaluation) or fall time (sensor evaluation) are measured.	
3 - MEASUREMENT	
The time to stop the alarm is measured (clear-down time). The time for the signal to go back to the baseline is measured (fall time).	
4 - APPLICABLE DOCUMENTS	
• User's manuals. • National SOP.	
5 – KEY EXPERIMENTAL PARAMETERS	
See Table 3 (see part 3.2.3).	
6 - EXPERIMENTAL CONSTRAINTS	
• Size and weight of the equipment. • In case of a dynamic generation, the contaminated flow must be higher than the sampling flow of the equipment. • Interface between the test rig and the equipment.	

ANNEX D EXAMPLES OF EXPERIMENTS FOR GAS/VAPOR FIELD-TESTING

The following T&E forms summarize some recommended experiments. These T&E forms are structured in the following five parts:

1. purpose of the experimentation;
2. general description of the experiment,
3. measurement during the experiment,
4. applicable documents,
5. key experimental parameters and quality assurance;
6. experimental constraints.

These T&E forms can be used as test plans or test reports.

The Table 10 describes which key parameters are evaluated in each T&E form.

Parameters	Form n°1	Form n°2
Time-to-alarm	x	
Clear-down time	x	
False negative probability P_{FN}	x	
False positive probability P_{FP}		x

Table 10: Summary of T&E forms

Chemical gas/vapor Point Detection Field Testing	Form n°1
Time-to-alarm + Clear-down time + False negative probability P_{FN}	***Basic T&E***

1 – PURPOSE

The purpose is to determine or verify the following parameters:

- time-to-alarm,
- clear-down time after the exposure,
- False Negative Probability P_{FN}.

2 - GENERAL DESCRIPTION OF THE EXPERIMENT

Vapor can be generated from calibrated gas bottles or evaporation of a liquid (by depositing liquid on (heated or not) surface, by using pyrotechnic methods, by using a controlled evaporation mixer, *etc.*).
Advantageously, some reference systems should be installed in different places in order to follow the moving of the cloud.
The equipment should be placed according the weather conditions, in order to optimize the possibilities for the detector to detect the cloud. Contamination aspects should be taken into account.

3 - MEASUREMENT

The time-to-alarm and the clear-down time are measured.
During the X repetitions, false negative alarms (FN) are counted: the P_{FN} is defined as the FN/X quotient.
If it is possible to know when the cloud is at the detector place (reference system), and if the frequency f of measurements is known (f = number of decisions / minute), during the exposure time (T), the equipment will have taken Y decisions (Y = f*T). False negative alarms (FN) are counted either by looking at the equipment during the test (be careful to safety of personal), or by using a remote control. The P_{FN} is defined as the FN/Y quotient. If the alarm algorithm is not known, it would be difficult to measure the number N of decisions taken by the DIM system (so Y too) and then not possible to calculate P_{FN}. Therefore, in this case, P_{FN} is only defined as FN during the exposure time.

4 - APPLICABLE DOCUMENTS

- User's manuals.
- National SOP (standard operating procedures).

5 – PARAMETERS AND QUALITY ASSURANCE

Key Parameters are exhaustively listed in Table 6.

Parameters	***Recommendations***	***Comments***
Purity of substance	To be maximized, for instance > 90 %	*From values of referenced or controlled analytical results.*
Temperature	None	*Temperature should be monitored.*
Humidity	None	*Humidity should be monitored.*
Wind conditions (speed and direction)	None	*Wind conditions should be monitored.*
Reference systems	None	*Name of systems, Frequency/Stability/Accuracy of measures, Calibration control (certificate).*
Number of experiments X	To be maximized to be statically representative: *e.g.* X ≥ 3 (preferentially: X ≥10)	-
Time between experiments	adapted to the CPD equipment under test.	*It is recommended to be longer than clear-down time.*

6 - EXPERIMENTAL CONSTRAINTS

To be noticed if necessary.

Chemical gas/vapor Point Detection Field Testing	Form n°2
False positive probability P_{FP}	***Basic T&E***

1 - PURPOSE

The purpose is to determine or verify the False Positive Probability P_{FP}.

2 - GENERAL DESCRIPTION OF THE EXPERIMENT

The equipment is placed outside:

- in natural atmosphere (to be *a minima* detailed);
- with smokes (whose nature should have been described).

At least an 8 hours-duration is recommended for each experiment in order to deal with a work or operational day.
The presence of natural interferents and their concentration should be monitored.

3 - MEASUREMENT

During the test under specified conditions, the CPD equipment will have taken N decisions. False positive alarms (FP) are counted either by looking at the equipment during the test, or by using a remote conditions. The P_{FP} is defined as the quotient FP/N.

4 - APPLICABLE DOCUMENTS

- User's manuals.
- National SOP (standard operating procedures).

5 – PARAMETERS AND QUALITY ASSURANCE

Key Parameters are exhaustively listed in Table 6.

Parameters	***Recommendations***	***Comments***
Temperature	None	*Temperature should be monitored.*
Humidity	None	*Humidity should be monitored.*
Wind conditions (speed and direction)	None	*Wind conditions should be monitored.*
Reference systems	None	*Name of the systems, Frequency of measures, Stability of measures, Accuracy of measures, Calibration control (calibration certificate).*
Number of experiments	X≥3 (preferentially: X≥10)	-

6 - EXPERIMENTAL CONSTRAINTS

To be noticed if necessary.

ANNEX E EXAMPLES OF EXPERIMENTS FOR GAS/VAPOR OPERATIONAL TESTING

This T&E form is structured in five parts:

1. purpose of the evaluation;
2. general description of the evaluation;
3. applicable documents;
4. quality assurance;
5. results.

This T&E form can be used as test plan. For the evaluation of one CPD equipment, it may be necessary to issue multiple T&E forms derived from the same template proposed below in order to evaluate all the different key parameters of paragraph 6.1.1 (*i.e.* issue one T&E form specifically dedicated to the evaluation of interoperability or of the maintenance system of the equipment, *etc.*)

Chemical gas/vapor Point Detection Operational Testing	Form
Name of the evaluation according to the key parameter to be evaluated (ex: Rules and Limits of employments – Interoperability, Logistics system, Infrastructure, *etc.*)	***T&E***

1 - PURPOSE

The purpose is to verify the effectiveness and suitability of the CPD equipment with respect to its intended use, *i.e.* confirm that the system fulfills the military requirements in real conditions, and to verify the reliability of equipment.

2 - GENERAL DESCRIPTION OF THE EVALUATION

Description of:

- the place and time/date of evaluation,
- when relevant, the threat substance (CWA, TIC) and/or artificial interferents involved,
- when relevant, the generation method of vapor for the threat substance and/or for the artificial interferents,
- the team conducting the evaluation (number and units of origin of personnel, their training levels, their military experience, *etc.*),
- the military equipment deployed for the evaluation (NVG, APCs, *etc.*),
- estimated length of time of the evaluation,
- specific safety measures according to national constraints.

3 - APPLICABLE DOCUMENTS

- User's manuals.
- National SOP (standard operating procedures).

4 – QUALITY ASSURANCE

	Recommendations	***Comments***
Purity of substance	None	*In some cases it should be primarily "operational relevant" to use substances of low purity.*
Temperature	None	*Temperature should be monitored.*
Humidity	None	*Humidity should be monitored.*
Wind conditions (speed and direction)	None	*Wind conditions should be monitored.*
Reference systems	None	*Name of the systems, frequency / stability / accuracy of measures, calibration control (calibration certificate).*
Number of experiments	None	-
Time between experiments	adapted to the equipment under test	-

5 – RESULTS

Description of the type of report to be issued and of its estimated date of issue.

ANNEX F COMPLEMENTARY TOOLS AS MODELING AND SIMULATION

F.1 SUGGESTED MODEL FOR GAS AND VAPOR

Two kinds of parameters can be described for CPD equipment like detectors:

a. operational performances which are intrinsic to the detector and the technology;

b. user constraints, like weight, dimensions, consumables needs, autonomy, *etc*.

Modeling and simulation (M & S) only deal with operational performances. M & S should describe how the equipment operates and which are the different parameters characterizing its performances. A CPD equipment can be modeled as a combination of several sensors with a data treatment unit (fusion of sensors results). Each sensor is sensitive to a unique linear combination of concentrations from environment. A sensor could be divided into the three following functions:

a. sampling function: determination of the linear combination of concentrations;

b. delay function: temporal effects (delay, mean value, …);

c. noise function: uncertainties of results.

Figure 3 describes functional scheme of a detector. All the different notations are listed below in “Variables and parameters” chapter.

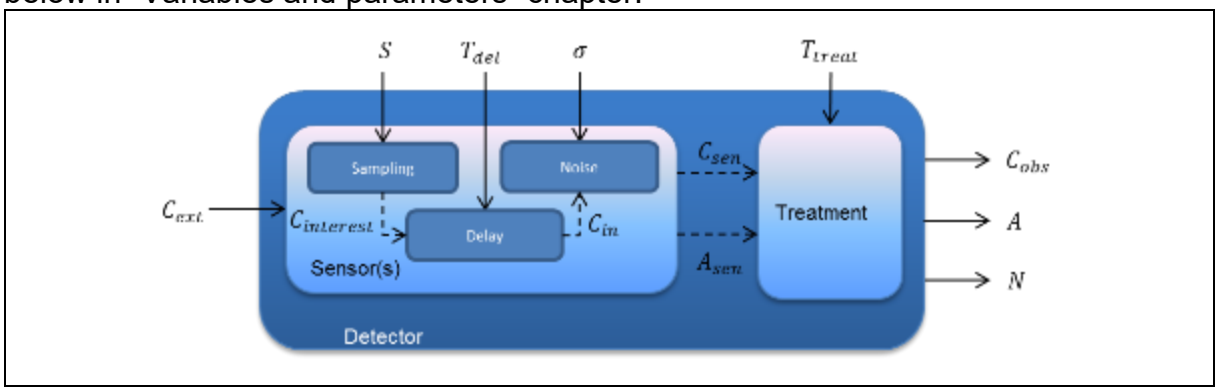

Figure 3: Functional scheme of a CPD equipment

F.2 VARIABLES AND PARAMETERS

F.2-1- Input parameters

An input parameter could be the instantaneous concentration of C substances in the air (C_{ext}). It is possible to define one C_{ext} by substance, background included.

F.2-2- Output parameters

Output parameters could be the following ones:

a. concentration measured by the equipment under test (Cobs);

b. Boolean alert (A) on “true” position if an alarm must be triggered;

c. number of enlightened diodes or bars on a bar graph (N).

F.2-3- State variables

State variables could be the following ones:

a. $C_{interest}$: the concentration that should be detected by the sensor (mean value in a stationary status);

b. C_{in}: internal concentration (mean-value in the time);

c. C_{sen}: concentration really measured by the sensor, by taking the background into account;

d. A_{sen}: Boolean alert, on “true” position if the sensor detects something.

Each sensor should give either C_{sen} or A_{sen} to the treatment unit.

F.2-4- Initialization parameters

M & S should be initialized by different initiation parameters like:

a. list of sensors;

b. how the internal concentration is calculated (*e.g.* perfect, mean or delayed models);

c. T_{del}: delay of the sensor to give an information (it does not exist for perfect model);

d. S: sensitivity to the substances;

e. Noise model: *e.g.* Gaussian, ROC curves ;

f. σ: standard deviation of the sensor noise, for Gaussian model;

g. CLOD: concentration that triggers off an alarm with a false negative probability of xx%;

h. ROC curves for each sensor;

i. T_{treat}: time of treatment that leads to a result;

j. Treatment models: *e.g.* Alert, Diodes / bars, Substances;

k. St_{sen}: list of the alarm levels for Alert and Diodes / bars models;

l. List of substances in Substances models.

For one CPD equipment, the instantiation of these initialization parameters should be done for each sensor, as shown in the following Table 11 for example (fictive CPD equipment with two sensors, with enlightened bars).

Sensor	Initialization parameter	Instantiation with suggested values for instance
Sensor 1	S (mg.m^{-3})	Substance 1: 0.5 ; substance 2: 0.6 ; substance 3: 2.0
	Delay model	*Delayed*
	T_{del}	15 s
	Noise Model	Gaussian
	σ	2.10^{-5} mg.m^{-3}
	Treatment model	Bars
	St_{sen}	0.1 ; 0.3 ; 0.6 ; 0.9 ; 1.2
Sensor 2	S (mg.m^{-3})	Substance 1: 0.2 ; substance 2: 0.8 ; substance 3: 1.0 ; substance 4: 0.5
	Delay model	*Delayed*
	T_{del}	15 s
	Noise Model	Gaussian
	σ	3.10^{-5} mg.m^{-3}
	Treatment model	Bars
	St_{sen}	0.05 ; 0.2 ; 0.4 ; 0.6 ; 0.8
Treatment unit	T_{treat} = 2 s	

Table 11: Examples of instantiation.

F.3- CONSTITUTIVE MODELS

F.3-1- Constitutive model of sensors

The concentration of interest ($C_{interest}$) could be a linear combination of the concentrations of each substance in the environment. The proportionality coefficient is the sensitivity to the substance:

$$C_{interest} = \sum_{substances} S^{substance} \times C_{ext}^{substance}$$

Equation 1: Sampling model

The internal concentration (C_{in}) is the concentration detected by a sensor. The reactivity of the sensor to give a final answer should be taken into account (T_{del}).
For *perfect* model:

$$C_{in} = C_{interest}$$

Equation 2: Perfect model

For a *mean* model:

$$C_{in}\,(t) = \frac{\int_{t-T_{del}}^{t} dt'\ C_{interest}(t')}{T_{del}}$$

Equation 3: Mean model

For a *delayed* model:

$$T_{del}\frac{d\,C_{in}}{dt} + \ C_{in} = C_{interest}$$

Equation 4: Delayed model

For the *Gaussian* model, a blank background B(t) should be defined (mean-value of zero, and its own standard deviation σ).

The concentration measured by the sensor could then be:

$$C_{sen} = \ C_{in} + B$$

Equation 5: Gaussian model

Boolean alert could be:

$$A_{sen} = (C_{sen} > C_{LOD})$$

Equation 6: Boolean alert

For ROC curves model, no C_{sen} could be calculated. Boolean alert A_{sen} is randomly defined with a probability read on the ROC curve (Detection probability = function of concentration).

F.3-2- Constitutive models of the treatment unit

The treatment unit should use data from each sensor, and also produce a measured value (C_{obs}, A or N) after a treatment time (T_{treat}).

In an *Alert* model, a calculation using A_{sen} should be done. For example, treatment unit could trig an alarm if one of the sensors gives an alarm.

In a *Diodes / bars* model, a calculation using C_{sen} should be done. For each sensor, the treatment unit will define the number of diodes or bars, through the different levels St_{sen}.

In a *Substances* model, a calculation using C_{sen} should be done. For each substance whose concentration can be calculated, the treatment unit will define the substance concentration $C_{obs}^{substance}$.

$$C_{sen} = \sum_{substances} S^{substance} \times C_{obs}^{substance}$$

Equation 7: Concentration measured by the detector

F.4- MODEL FOR LIQUID / SOLID (BULK SUBSTANCE)

Detector model will concern only surface contamination, because no model exists for detectors dedicated to bulk substance.

This paragraph will be detailed later in future versions of this Volume II.

F.5- MODEL FOR SURFACE CONTAMINATION

This paragraph will be detailed later in future versions of this Volume II.

F.6- MODEL FOR AEROSOLS

This paragraph will be detailed later in future versions of this Volume II.

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