THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**ION MOBILITY SPECTROMETER**
APPLICATION:	**DETECTION OF CHEMICAL WARFARE AGENTS AND TOXIC INDUSTRIAL CHEMICALS**
TECHNOLOGY NAME:	**RAID-M**
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The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies. Information and ETV documents are available at www.epa.gov/etv.

ETV works in partnership with recognized standards and testing organizations, with stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

Subsequent to the terrorist attacks of September 11, 2001, this ETV approach has been applied to verify the performance of homeland security technologies. Monitoring and detection technologies for the protection of public buildings and other public spaces fall within the Safe Buildings Monitoring and Detection Technologies Verification Program, which is funded by EPA and conducted by Battelle. In this program, Battelle recently evaluated the performance of the Bruker Daltonics Inc. RAID-M portable ion mobility spectrometer (IMS). This verification statement, the full report on which it is based, and the test/QA plan for this verification are available through a link on the ETV Web site (www.epa.gov/etv/centers/center11.html).

VERIFICATION TEST DESCRIPTION

The objective of this verification test of the RAID-M, a commercially available, portable IMS, was to evaluate its ability to detect toxic chemicals and chemical agents in indoor air. This verification focused on the scenario of a portable IMS used by first responders to identify contaminants and guide emergency response activities after chemical contamination of a building. The following performance characteristics of the RAID-M were evaluated: response time, recovery time, accuracy, response threshold, repeatability, temperature and humidity effects, interference effects, cold-/hot-start behavior, battery life, and operational characteristics. Repeatability was assessed for RAID-M responses, response times, and recovery times.

This verification test took place between August 6 and December 18, 2003. Two units of the RAID-M IMS were tested simultaneously in most parts of this verification; in some cases, failure of a RAID-M required that testing continue with just one instrument. Response time, recovery time, accuracy, and repeatability were evaluated by challenging the RAID-Ms with known vapor concentrations of target toxic industrial chemicals (TICs) and chemical warfare (CW) agents. RAID-M performance at low target analyte concentrations was evaluated to assess the response threshold. Similar tests conducted over a range of temperatures and relative humidities (RHs) were used to establish the effects of these factors on detection capabilities. The effects of potential interferences in an emergency situation were assessed by sampling selected interferences both with and without the target TICs and CW agents present. The RAID-Ms were tested with a single TIC after a cold start (i.e., without the usual warm-up period) from room temperature, from cold storage conditions (5°C), and from hot storage (40°C) to evaluate the delay time before readings could be obtained and the response speed and accuracy of the RAID-Ms once readings were obtained. Battery life was determined as the time until RAID-M performance degraded as battery power was exhausted, in continuous operation. Operational factors such as ease of use, data output, and cost were assessed by observations of the test personnel and through inquiries to the vendor.

Testing was limited to detecting chemicals in the vapor phase because that mode of application is most relevant to use by first responders. Testing was conducted in two phases: detection of TICs (conducted in a non-surety laboratory at Battelle) and detection of CW agents (conducted in a certified surety laboratory at Battelle's Hazardous Materials Research Center). The TICs used in testing were cyanogen chloride (ClCN; North Atlantic Treaty Organization [NATO] military designation CK), hydrogen cyanide (HCN; designated AC), phosgene ($COCl_2$; designated CG), chlorine ($C1_2$; no military designation), and arsine (AsH_3; designated SA). The CW agents were sarin (GB) and sulfur mustard (HD). The RAID-Ms were not programmed to respond to SA, so testing with that TIC was minimal.

For relevance to use by first responders, most test procedures were conducted with challenge concentrations of the TIC or CW agent that were at or near immediately dangerous to life and health (IDLH) or similar levels. Table 1 summarizes the challenge concentrations used in testing. Response thresholds were tested by repeatedly stepping down in concentration, starting from IDLH levels.

QA oversight of verification testing was provided by Battelle and EPA. Battelle QA staff conducted a technical systems audit (TSA), a performance evaluation audit, and a data quality audit of all the test data. An independent TSA was also conducted by EPA.

Table 1. Target TIC and CW Agent Challenge Concentrations

Chemical	Concentrations	Type of Level
Hydrogen cyanide (AC)	50 ppm (50 mg/m^3) and 5 ppm (5 mg/m^3)	1 and 0.1 x IDLH[a]
Cyanogen chloride (CK)	20 ppm (50 mg/m^3) and 2 ppm (5 mg/m^3)	1 and 0.1 x IDLH
Phosgene (CG)	2 ppm (8 mg/m^3) and 0.2 ppm (0.8 mg/m^3)	1 and 0.1 x IDLH
Chlorine (Cl_2)	10 ppm (30 mg/m^3) and 1 ppm (3 mg/m^3)	1 and 0.1 x IDLH
Arsine (SA)	3 ppm (10 mg/m^3)	1 x IDLH
Sarin (GB)	0.014 ppm (0.080 mg/m^3)	0.4 x IDLH
Sulfur mustard (HD)	0.063 ppm (0.42 mg/m^3)	0.7 x AEGL-2[b]

(a) IDLH = Immediately Dangerous to Life and Health; IDLH value for CK estimated from value for AC.

(b) AEGL = Acute Exposure Guideline Level; AEGL-2 levels are those expected to produce a serious hindrance to efforts to escape in the general population. The AEGL-2 value of 0.09 ppm (0.6 mg/m^3) for HD is based on a 10-minute exposure.

TECHNOLOGY DESCRIPTION

The following description of the RAID-M was provided by the vendor and does not represent verified information.

The RAID-M is a chemical detector that uses the principle of IMS to detect, classify, quantify, and continuously monitor concentrations of CW agents and TICs. The identity of substances detected is displayed both by class (e.g., “G,” “H,” or “T,” for G series agents, H series agents, and TICs, respectively) and by specific agent, simulant, or TIC (e.g., “GB,” “HD,” or “TDI”). All classes can be displayed independently. Relative concentrations are indicated by a bar display with eight increments. In addition to use in the field, the RAID-M is designed to be capable of operating within collective protection facilities.

The RAID-M can be operated while being held in one hand. It has no protruding parts and weighs less than 2.80 kilograms (6.4 pounds), excluding battery. The RAID-M contains a small radioactive sealed source that is completely housed and is such that RAID-M can be stored in bulk. The RAID-M is 400 millimeters (mm) (15.7 inches) long, 115 mm (4.5 inches) wide, and 165 mm (6.5 inches) high. The RAID-M is of a one-tube design, with automatic polarity switching (i.e., both positive and negative ions are automatically monitored, in alternate intervals of 2 to 3 seconds), and is fully microprocessor-controlled. It has a remote display and control option. The display shows agent identity and a relative indication of hazard level. The RAID-M incorporates a built-in audible alarm to indicate agent detection, and visual alarms to warn of a low battery and other faults.

The RAID-M is powered by an integral, primary battery and can accept power input from a variety of sources including vehicles (12- to 24-volt DC nominal) or a 240-volt, 50-Hertz, alternating current power supply. A diagnostic input/output socket provides data output, power input, personal computer connectivity, and built-in test information. The carrying case is designed to protect the RAID-M from exposure to air blasts, thermal radiation, neutron radiation, gamma radiation, and electromagnetic pulse.

Consumables do not need to be changed when the RAID-M detects a challenge, and consumables are designed to have a maximum life of not less than 500 hours. There are no scheduled preventive maintenance tasks. Daily checks are designed to not require dismantling the equipment and to not typically exceed an average of 10 minutes per day.

VERIFICATION OF PERFORMANCE

Table 2 summarizes quantitative results for key RAID-M performance parameters. Additional information and the results of various qualitative evaluations are presented in the subsequent paragraphs.

Table 2. Summary Results for Key Performance Parameters

Performance Parameter	TICs				CW Agents	
	AC	CK	CG	Cl_2	GB	HD
Response time (seconds)	3 to 5	3 to 5	3 to 5	9	10	5 to 8
Recovery time (seconds)	15 to >600	10 to 40	<10	10 to 40	15 to 70	10 to 100
Identification accuracy (%)	nearly 100	nearly 100	nearly 100	nearly 100	97.5	99.4
Response threshold (ppm)	<0.06	<0.6	0.08 to 0.33[a]	0.25 to 0.5[a]	0.0035 to 0.007[a]	0.01 to 0.02[a]
Interferent effects: False negatives[b]				Latex paint fumes, floor cleaner vapors	Latex paint fumes, floor cleaner vapors, air freshener vapors	Latex paint fumes, air freshener vapors, DEAE,[c] gasoline exhaust hydrocarbons

[a] Range shown is based on results from two different RAID-M units.
[b] The indicated interferents reduced or eliminated response to the indicated TIC or CW agent. See text below.
[c] N,N-diethylaminoethanol.

Response Time: Over the ranges of 5 to 35°C and <20 to >80 percent RH, temperature and RH had minimal effect on response time for any TIC or CW agent. Response times for AC were also unaffected by operating the RAID-M from a cold start (i.e., with insufficient warm-up time).

Recovery Time: Recovery times for AC ranged from 15 seconds to over 600 seconds, with the fastest recovery times occurring at low concentrations and high temperatures. In operation from a cold start, the recovery time for AC was lengthened to at least 600 seconds. Recovery times for GB and HD averaged about 50 seconds and about 34 seconds, respectively, at room temperature, with average recovery times reduced by about half at higher temperatures. RH had minimal effect on recovery times.

Accuracy: The RAID-Ms were 100% accurate in identifying the TIC being sampled under almost all test conditions. Accuracy for the CW agents was also high: overall accuracy for GB was 97.5% (excluding data from interferences that suppressed GB response), and for HD was 99.4%, when all test data were included. In addition to correctly identifying GB and HD, the RAID-Ms usually also displayed “HN” (the designation for nitrogen mustard) when sampling either of these agents. For both TICs and CW agents, accuracy was essentially the same when alternating between different challenge concentrations as when alternating between clean air and a challenge concentration. Accuracy below 100% occurred primarily for CK, with the lowest accuracy (~50%) at high humidity and low temperature. The inaccuracy for CK occurred in the form of misidentification of CK as chlorine gas (Cl_2).

Repeatability: Repeatability of response for AC was perfect, as full-scale readings consistently resulted at the test concentrations. The percent relative standard deviation (%RSD) of recovery times was low for AC primarily because of the long average recovery times for that TIC under many conditions. Response and recovery times were most variable for CK. RAID-M readings and recovery times for Cl_2 were strongly affected by RH, with the most variability at high humidity. For the CW agents, the repeatability of RAID-M response to HD improved as temperature increased, but the repeatability of response time and recovery time for HD lessened. Repeatability of response for GB did not vary substantially with test conditions, and the only effect on repeatability was that recovery times for GB were less repeatable at high humidity.

Temperature and Humidity Effects: Temperature and RH had little effect on RAID-M response to the TICs and CW agents. Higher readings for CK were generally found at lower temperatures, and higher readings for CK and Cl_2 were generally found at lower humidity. Slightly higher readings for both CW agents were also found at lower temperatures.

Interferent Effects: In terms of false negatives, RAID-M response for Cl_2 was sharply reduced by latex paint fumes and floor cleaner vapors; the floor cleaner vapors resulted in zero response for Cl_2. Response to GB was sharply reduced by latex paint fumes, floor cleaner vapors, and air freshener vapors; the latter two interferents resulted in zero response for GB. Response for HD was reduced by about half by latex paint fumes, air freshener vapors, N,N-diethylaminoethanol (DEAE), and gasoline engine exhaust hydrocarbons. However, the interferents also caused the RAID-Ms to display indications of other agents, including the organophosphate nerve agents VX and tabun (GA). False positive responses occurred only with floor cleaner vapors and DEAE. Both of these interferents produced small positive responses in about one-third of the trials; in those cases the RAID-Ms incorrectly identified the interferent as the nerve agent VX.

Cold-/Hot-Start Behavior: Operating the RAID-M with insufficient warmup time reduced the initial responses to AC, regardless of whether the cold start occurred after storage at 5°C, at room temperature, or at 40°C. The response time for AC was not affected by operating from a cold start, but the recovery time was lengthened in such operation. The delay time before a reading could be obtained ranged from 40 seconds to about 3 minutes, except for one unit that showed a delay time of nearly 14 minutes after a 40°C storage and cold start.

Battery Life: The useful operating life for fully charged batteries in two RAID-M units in continuous operation was found to be 6 hours 29 minutes, and 7 hours 52 minutes, respectively.

Operational Characteristics: Several operational characteristics of the RAID-M were noted during testing. In general, the RAID-M was easy to use, gave clear alarms and a readable and informative display, and provided error and diagnostic messages. The RAID-M automatically switched between positive and negative ion detection modes at intervals of a few seconds, allowing detection of a wide variety of chemicals. Among the most important other operational characteristics were

- The use in the RAID-M of two separate software libraries, one for TICs and one for CW agents, necessitating switching between libraries to detect both types of chemicals.
- The need for three types of consumables (carbon backflush filter, drying tube, and ammonia dopant), the first two of which needed to be replaced several times during the nearly five-month test period. RAID-M error messages calling for replacement of consumables are based on metered time of use, not on the actual state of the consumable.
- The need for proper warm-up of the RAID-M before use, to assure that full response is achieved when monitoring starts.
- The failure during testing of two of the three RAID-Ms used in this verification, one due to an electrical fault, and the other to an apparently incorrect error message that required overriding the message by connection to a laptop computer.

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