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National Defence
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DEVELOPMENT OF PAPER, CHEMICAL AGENT DETECTOR, 3-WAY LIQUID CONTAINING NON-MUTAGENIC DYES.

I-REPLACEMENT OF THE YELLOW DYE THIODIPHENYL-4,4′-DIAZO-bis-SALICYLIC ACID (A2)

by

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
REPORT NO. 962

PCN
0513J11

June 1988
Ottawa

ABSTRACT

The Paper, Chemical Agent Detector, 3-Way Liquid is used by the Canadian Forces for the detection of liquid chemical warfare agents and is supplied by Canada to many Western countries. Unfortunately, two of the three dyes used in the detector paper have been found to be mutagenic and thus a project was initiated to find non-mutagenic replacement dyes. This report describes the work leading to the replacement of dyestuff A2, which is currently used to detect G-type nerve agent liquid droplets. Candidate replacement dyes were either procured commercially or synthesized when not available commercially. Two good, non-mutagenic, replacement dyes for A2 have been found, namely Disperse Yellow 23 and p-ethoxyphenyl-azo-α-hydroxynaphthoic acid. These dyes were incorporated into paper, both alone and in the presence of the dyes used for detection of mustard and V-type nerve agents. Various dye loadings were used. Based on the results obtained, Disperse Yellow 23 was recommended as the replacement for the current dye A2. This dye gave brighter yellow responses than A2 and the other candidate replacement dye. Detector paper made with this dye is capable of detecting smaller droplets of G-type nerve agents.

RÉSUMÉ

Le Papier Détecteur d'Agents Chimiques Liquides "3-Way" est utilisé par les Forces Armées Canadiennes pour la détection des armes chimiques liquides et est fourni par le Canada à plusieurs pays de l'Ouest. Malheureusement, deux des trois colorants utilisés dans le papier détecteur se sont avérés être des composés mutagènes et ainsi un projet a été initié en vue de trouver des colorants substituts non mutagènes. Ce rapport décrit le travail accompli pour le remplacemant du colorant A2 présentement utilisé pour détecter des gouttelettes d'agents chimiques de type G. Les colorants étudiés ont soit été obtenus de source commerciale ou synthétisés dans nos laboratoires. Deux colorants se sont avérés être d'excellents candidats pour le remplacement de A2, en l'occurence Disperse Yellow 23 et l'acide p-éthoxyphényl-azo-α-hydroxynaphthoique. Ces colorants ont été incorporés dans le papier à diverses concentrations, d'abord séparément, puis ensuite en présence des colorants utilisés pour la détection du gaz moutarde et des agents chimiques de type V. D'après les résultats obtenus, Disperse Yellow 23 a été recommandé pour remplacer le colorant A2 présentement utilisé. Ce colorant, qui n'est pas mutagène, a donné des réponses jaunes plus vives comparativement à A2 et à l'autre candidat de remplacement et ce à des concentrations plus faibles. Le papier détecteur fait avec ce colorant est capable de détecter de plus petites gouttelettes d'agents chimiques de type G.

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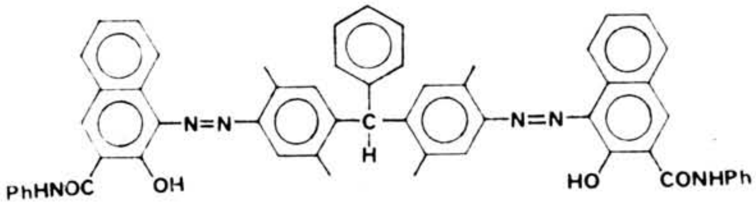
1.0 INTRODUCTION

1.1 Background

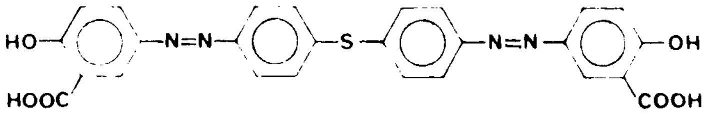
The Paper, Chemical Agent Detector, 3-Way Liquid (commonly called 3-Way paper) developed in the early 1960's at DREO (1,2) for the detection of liquid chemical warfare agents, has been very successful and is now a standard item for the Canadian Forces and the military of 17 other Western Nations. The detector consists of a paper in which three dyes have been incorporated, each being capable of detecting a particular family of liquid chemical warfare agent droplets. Chemical agent droplets produce coloured spots on the paper by interaction with the three dyes and the type of CW agent may be identified by the colour produced. Thus, the soldier has a direct method of determining if he, his equipment, or the area around him, is contaminated with these toxic materials.

The three dyes presently incorporated into the 3-Way Detector Paper are E (1), A2 (2) and EDA (3):



1

2,5,2',5'-Tetramethyltriphenylmethane-4,4'-diazo-bis-β-hydroxynaphthoic anilide (commonly called E)



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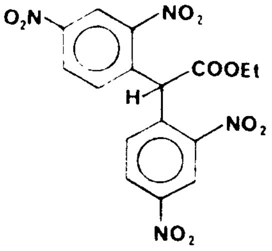
Thiodiphenyl-4,4'-diazo-bis-salicylic acid (commonly called A2)



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Ethyl-bis-(2,4-dinitrophenyl) acetate (commonly called EDA)

Two of the dyes, E and A2, exhibit different solubility characteristics towards agents; liquid H agent (mustard) dissolves the red dye E and liquid G nerve agents dissolve the yellow dye A2. The third dye EDA works by a pH dependent colour change and is an indicator dye. In the presence of bases such as V nerve agents, the proton attached to the central carbon of EDA is removed and the resulting negative charge is delocalized in the phenyl rings to produce an intense blue colour. Because V agents also dissolve the yellow dye, the final response of the paper is a dark green colour.

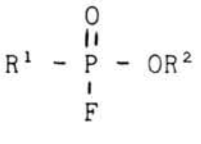
Unfortunately, two of the dyes used in the detector paper have been found to be mutagenic (3). EDA was found to be strongly mutagenic while A2 was moderately mutagenic. Despite the fact that military personnel who attach these papers routinely to their uniforms and equipment have a very low exposure to the impregnated dyes, the problem is crucial for people who are involved in the detector paper manufacturing, i.e. where these dyes have to be handled and ground in kilogram quantities. With mutagenic dyes special protective equipment must be used by industrial workers while manufacturing and grinding the dyes to the required particle size. Special precautions must be taken while loading dye powders into paper-making equipment while the "white water" from the paper making operation can't be dumped until all dye fines are removed. These difficulties have led to a refusal by Canadian industry to continue detector paper manufacture. Therefore, to insure a continuing capability to manufacture the detector paper in Canada, the development of an improved paper containing non-mutagenic dyes was undertaken.

This report deals with the search for a replacement for the yellow dyestuff A2.

1.2 Requirements for the Replacement of Dyestuff A2

The yellow dye incorporated into the 3-way paper is used for the detection of G nerve agents. A replacement dye must meet the following requirements:

1. It must be non-mutagenic;
2. The dye must be yellow when it dissolves in liquid G nerve agents. The yellow colour must be as strong as possible for high contrast with the background neutral colour (light grey to light beige) of the paper;
3. It must be stable enough to give a paper with a good shelf life;
4. It must be soluble in phosphate esters of general formula:



$$R^1 - \overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle F}{|}}{P}} - OR^2$$

GD; $R^1=CH_3$, $R^2=CH(CH_3)C(CH_3)_3$
GB; $R^1=CH_3$, $R^2=CH(CH_3)_2$

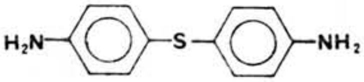
5. It must be insoluble in water since the dye is to be incorporated into paper using standard paper making technology and equipment;

6. It must remain solid during the paper drying step (without sublimation) and also during any spray drying which may be required to agglomerate fines. Thus, the melting point must be greater than 100°C;

7. It is highly desirable that it be insoluble in liquids which are likely to be encountered on the battlefield, such as petroleum products, antifreeze solutions and alcohol solutions.

The above requirements are stringent and many yellow dyes have been procured and synthesized for evaluation against these criteria (vide infra). The first requirement, that of non-mutagenicity, is the most difficult to predict in advance. Certain chemical structures and functional groups are known to be potent mutagens but a well defined structure-reactivity relationship is still lacking. This topic was recently reviewed (4).

We believe that dyestuff A2 is moderately mutagenic because it contains the thiobenzidine (4) moiety, a compound that can be liberated via a reductive metabolic cleavage of the dye. This chemical substance,



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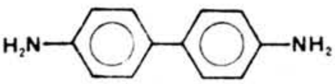
along with the structurally related benzidine (5) analogues, are known to be highly mutagenic (5-7).



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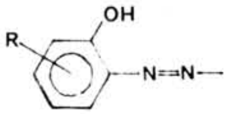
All commercial dyestuffs containing these chemical features are presently prohibited on the U.S. market (7).

Several other structural features which are frequently encountered in synthetic azo (-N=N-) dyes are also known to be associated with potent mutagenicity (5-8). For example, dyes which contain moieties such as *o*-azophenols (6), 1-azo,2-naphthols (7), 1-azonaphthalenes (8), (*p*-dimethylamino-phenylazo) phenyls (9) and nitrophenyls (10) (8) are among the most mutagenic dyes (5-8).



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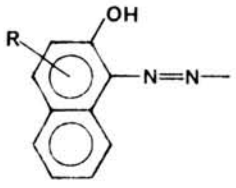

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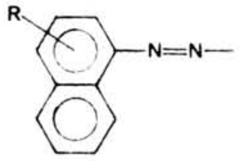

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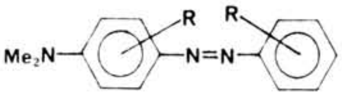

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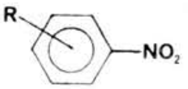

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Although the above mutagenicity considerations ruled out many yellow dyes, literature sources (e.g. 9-11) suggested that several dyes from commercial or synthetic sources might posses the requisite properties for A2 replacement.

2.0 RESULTS AND DISCUSSION

2.1 Evaluation of Commercial Dyes

A series of commercial dyes were selected for evaluation based on the criteria listed above. Some dyes were tested even though they were actually suspected to be mutagenic or carcinogenic. The main reason for testing these dyes was to utilize the observations later for the selection of non-commercially available dyes for synthesis (vide infra). Physical characteristics like melting point, solubility in hot and cold water, and response with simulants and agents were determined. Promising candidate dyes were incorporated into handsheets.

The results, outlined in Table 1, show that all of the commercial dyes evaluated for A2 replacement, except one, were rejected because of water solubility and/or lack of response to G simulant (methyl cellosolve) and GD. The one exception was Disperse Yellow 23 (20) (entry 10). This dye was insoluble in water and gave a very good yellow response with G simulant and with liquid GD.

This candidate was incorporated into handsheets (0.2 and 1.0% dye loadings) in the presence of E (0.75%) and TBPE (1.0%)[a] (see Appendix 1, entries 1 and 2) and the papers obtained were tested with agents. They gave proper colour responses with drops of agents, i.e. red with HD, dark yellow with GD, and dark green with VX[b]. These handsheets were also tested with drops of the current simulants from the Training Kit, CW Agent Detector, Liquid and Vapour. The H simulant gave the proper red colour while the V simulant gave dark blue instead of the expected dark green. Also, the G simulant gave a light green colour instead of the required dark yellow. This is attributed to the fact that TBPE has a low pK value (colour change, yellow to blue at pH = 3.6 - 4.2) and partially changes colour when treated with G simulant[c]. This work shows that the simulants for G and V will need to be changed to give the correct colours when the paper containing the new non-mutagenic dyes is in-service with the Canadian Forces.

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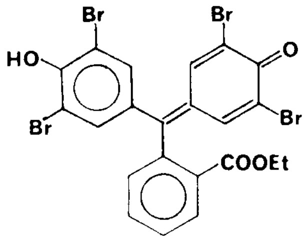
[a] 3',3'',5',5''-tetrabromophenolphthalein ethyl ester, designated TBPE (22) by us, is the non-mutagenic indicator dye which is the recommended candidate to replace the strongly mutagenic dye EDA which is used to detect VX. A separate report (12) has been written on the replacement of EDA.



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[b] TBPE gives a dark blue colour with VX but, since VX also dissolves some of the yellow dye, Disperse Yellow 23, the resultant response is a dark green.

[c] The G simulant gives the proper dark yellow colour when only Disperse Yellow 23 is present.

TABLE 1

Commercially Available Yellow Dyes Investigated for A2 Replacement[a]

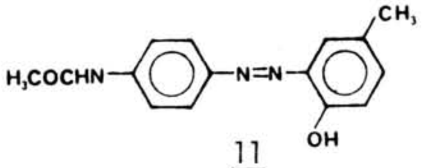
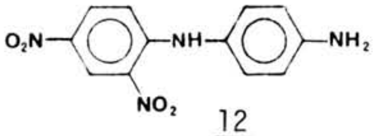
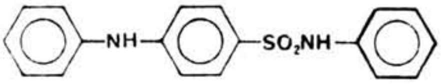
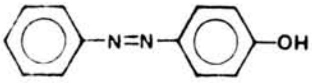
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response[b,c]	Agent Response(GD)[c]	Handsheets[d]		Mutagenticity	Comments
						Background Colour	Agent Response		
1	 11 Disperse Yellow 3 (Aldrich, 30%)	✓	X	✓					Rejected; water soluble
2	 12 Disperse Yellow 9 (Aldrich, 85%)	✓	✓	X					Rejected; no colour with simulant
3	 13 Disperse Yellow 42 (Aldrich)	✓	X	X					Rejected; water soluble, slow response with simulant
4	 14 Solvent Yellow 7 (Aldrich)	✓	X	✓ ✓	✓ ✓				Rejected; water soluble

TABLE 1 (Cont'd)

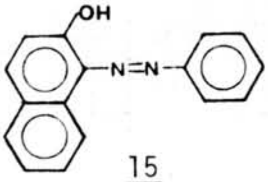
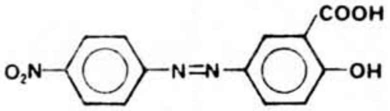
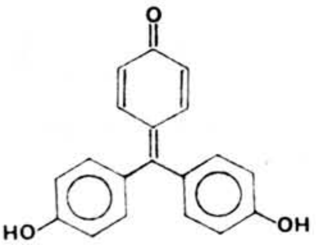
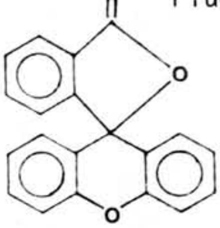
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response b,c	Agent Response(GD) c	Handsheets d		Mutagenicity	Comments
						Background Colour	Agent Response		
5	 15 Solvent Yellow 14 (Aldrich)	✓	✓	✓ ✓					Rejected; cancer suspect agent
6	 16 Mordant Orange 1 (Aldrich, 80%)	✓	X	X				X	Rejected; water soluble, orange response mutagenic (6)
7	 17 Rosolic Acid (Aldrich, 85%)	✓	X	✓ ✓					Rejected; water soluble
8	Fluorescein  18 Solvent Yellow 94 (Aldrich, 95%)	✓	X X	X					Rejected; very soluble in cold water, slow response with simulant

TABLE 1 (Cont'd)

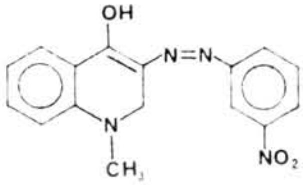
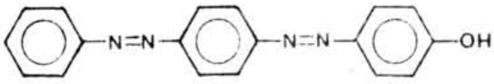
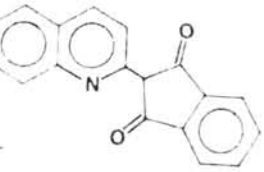
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response b,c	Agent Response(GD) c	Handsheets d		Mutagenicity	Comments
						Background Colour	Agent Response		
9	 19 Disperse Yellow 5 (Atlantic Chemical Corp.)	✓	X	✓	✓				Rejected; slightly soluble in cold water
10	 20 Disperse Yellow 23 (Atlantic Chemical Corp.)	✓	✓	✓ ✓	✓ ✓	✓	✓ ✓	✓	Very good yellow response with simulant and GD, non- mutagenic
11	 21 Solvent Yellow 33 (Atlantic Chemical Corp.)	✓	X ✓	✓	X				Rejected; slightly soluble in water, light yellow response with GD
12	Unknown Structure Disperse Yellow 56 (Atlantic Chemical Corp.)	✓	X	X	X				Rejected; water soluble, light yellow response with GD

TABLE 1 (Cont'd)

Entry No.	Structure	Melting Point	Water Solubility	Simulant Response[b,c]	Agent Response(GD)[c]	Handsheets[d] Background Colour	Handsheets[d] Agent Response	Mutagenicity	Comments
13	Unknown Structure Disperse Yellow 54 (Atlantic Chemical Corp.)	✓	X	X	X				Rejected; no colour with GD
14	Unknown Structure Mordant Yellow A3 (Atlantic Chemical Corp.)	✓	✓	X	X				Rejected; light yellow response with simulant and GD
15	Unknown Structure Mordant Yellow A4 (Atlantic Chemical Corp.)	✓	✓	X	X				Rejected; light yellow response with simulant and GD
16	Unknown Structure Mordant Yellow A5 (Atlantic Chemical Corp.)	✓	✓	X	X				Rejected; no colour with simulant or GD

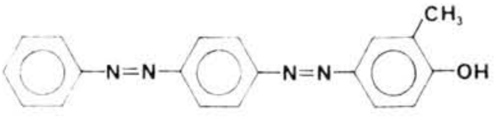
[a] A check mark (✓) is used for a satisfactory test while an X indicates a failed test.

[b] The simulant for G agents is methyl cellosolve.

[c] Compounds were rubbed on filter paper for the test.

[d] Handsheets were made by incorporating the yellow dye with E (0.75%) and TBPE (1.0%).

No information could be found in the literature on the mutagenic properties of Disperse Yellow 23. The literature does report, however, that a related compound called Disperse Yellow 7 is non-carcinogenic (6). The difference between Disperse Yellow 23 and Disperse Yellow 7 is an extra methyl group which should not change the mutagenic properties. A sample of Disperse Yellow 23 was sent to the Ontario Research Foundation (ORF) for mutagenicity testing using the Ames Salmonella/mammalian microsomal mutagenicity plate incorporation assay. Results showed that Disperse Yellow 23 was negative (non-mutagenic) for the five Salmonella tester strains, both in the presence and absence of metabolic activation (14).



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Since Disperse Yellow 23 is a non-mutagenic dye, can be easily incorporated into handsheets in the presence of E and TBPE and gives a very good yellow response with GD with dye loading as low as 0.2%, a more detailed investigation was undertaken in order to further assess the dye as a replacement for A2. The purpose of this study was to determine the appropriate loading and particle size of this dye for efficient incorporation into paper and to ascertain the sensitivity of the paper to droplets of agent as small as 100 µm (15). Disperse Yellow 23 was ground dry through a #250 mesh screen (see Experimental). Handsheets with Disperse Yellow 23 (20) with dye loadings ranging from 0.2 to 0.8% were made and tested with 100-110 µm droplets of GD. The results of the testing, which are presented in Appendix 1 (entries 3-6) showed that handsheets with dye loading of Disperse Yellow 23 as low as 0.4% to 0.6% gave excellent yellow responses when tested with these droplets of GD. This result was gratifying since the current 3-Way Paper cannot detect such small droplets of G agent even at a dye loading of 1.2%.

This work established that a dye loading of Disperse Yellow 23 of 0.6% appeared to be suitable. The next step was to make handsheets incorporating E 0.75%, Disperse Yellow 23 0.6% and various dye loadings of TBPE (0.2 to 1.2%) so that the sensitivity of these 3-Way handsheets towards very small droplets (100-110 µm) of the agents HD, GD and VX could be determined. At the same time, the required dye loading of TBPE to produce the desired dark green response with VX could be established. The results obtained are presented in Appendix 1 (entries 7 to 12) and show that both the red dye E and the yellow dye Disperse Yellow 23 can detect 100-110 μm droplets of HD and GD with dye loadings of 0.75% and 0.6% respectively. The blue indicator dye TBPE can also detect 100-110 μm droplets of VX but the dye loading should be at least 0.8% or preferably 1.0% in order to give the required dark green response. Dye loadings of TBPE ranging from 0.4% to 0.6% gave only a green to light green response while dye loading of 0.2% gave only a yellow colour.

Analytical methods to determine the contents of the dyes[a] in the 3-way handsheets also were developed (see Experimental section). Several handsheets were analyzed and the results are reported in Appendix 1 (entries 9 to 12). The retention of each dye in the paper was shown to be good to excellent and was approximately 82-96% for E, 48-67% for Disperse Yellow 23 and 60-75% for TBPE.

As shown by the above results, Disperse Yellow 23 is a suitable replacement dye for A2. It is commercially available and is non-mutagenic. It can be successfully incorporated into handsheets in the presence of E and TBPE and can detect 100-110 μm agent droplets of GD.

2.2 Evaluation of Dyes Requiring Synthesis

During our literature search for A2 replacement candidates, several dyes which were not commercially available appeared to be of interest. Some of these dyes were similar to A2, i.e. derivatives of azo-salicylic acid (<u>24</u>) or azo-<u>α</u>-hydroxynaphthoic acid (<u>25</u>) (16,17) while others were merocyanine type dyes, particularly <u>p</u>-dialkylamino-benzylidene derivatives of active methylene compounds (<u>26</u>) (18-20). The dyes, whose structures are shown in Table 2, were prepared according to literature methods and tested as described previously for the commercially available dyes.

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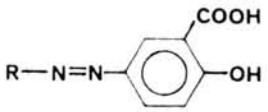
[a] The dye loading is defined as the weight percent of the dye added during the process of making paper while the dye content is the actual weight percent of the dye retained in the paper.



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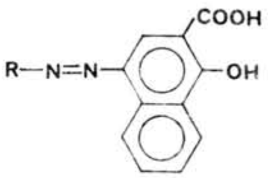

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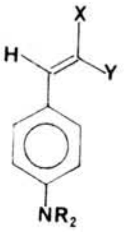

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X,Y = electron withdrawing groups

As can be seen from Table 2, analogues of phenylazosalicylic acid (entries 1-3) were all rejected because of the fact that these were significantly soluble in water. Attempts to render these materials insoluble by making amide or ester derivatives from them (entries 4-6) were also unsuccessful. Analogues of benzene-azo-α-hydroxynaphthoic acid (entries 7 and 8) were found to be more promising since the bulkiness of the aromatic acid moiety considerably reduced their water solubility. Entry 8, p-ethoxyphenylazo-α- hydroxynaphthoic acid (34), called PEN by us, was of special interest. This dye was insoluble in both hot and cold water and gave a very fast yellow response with G simulant and liquid GD. It was incorporated into handsheets (0.1 and 0.8% dye loading) in the presence of E (0.75%) and TBPE (1.0%) (see Appendix 2, entries 1 and 2) without producing any significant background colour in the paper. The handsheets gave proper colour responses to liquid agents, i.e. red with HD, yellow with GD and dark green with VX. These handsheets were also tested with drops of simulants. While a proper colour response was obtained with the simulant for H (red), a green response was obtained with G simulant (as previously encountered with Disperse Yellow 23) and the paper gave a dark blue instead of the required dark green with V simulant.

This yellow dye was predicted to be non-mutagenic since a very similar dye, Solvent Red 3 (44), is non-carcinogenic (6). A sample of PEN (34) was sent to the Ontario Research Foundation (ORF) for mutagenicity

TABLE 2

Yellow Dyes Synthesized for Investigation as A2 Replacements[a]

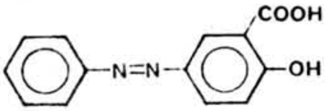
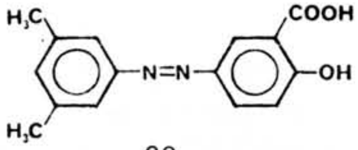
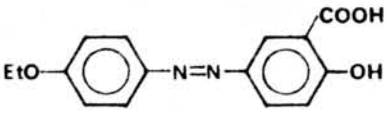
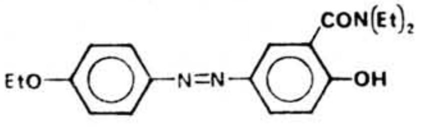
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response [b,c]	Agent Response(GD) [c]	Handsheets [d]		Mutagenicity	Comments
						Background Colour	Agent Response		
1	 27 Ref. 16	✓	X	✓					Rejected; water soluble
2	 28 Ref. 15	✓	X	✓					Rejected; water soluble
3	 29 Ref. 17	✓	X	✓ ✓					Rejected; water soluble
4	 30	X	X						Rejected; water soluble, melting point too low

TABLE 2 (Cont'd)

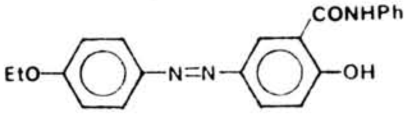
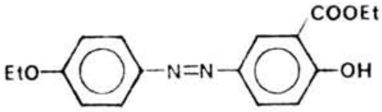
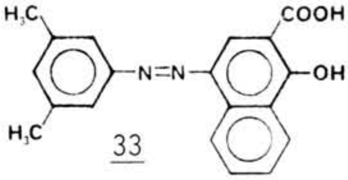
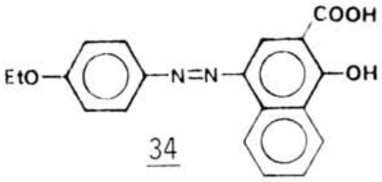
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response b,c	Agent Response(GD) c	Handsheets d		Mutagenicity	Comments
						Background Colour	Agent Response		
5	 31	✓	X	✓					Rejected; water soluble
6	 32	X		X					Rejected; melting point too low, brown response with simulant
7	 33 Ref. 17	✓	✓	✓	X	X			Rejected; brown background colour on handsheets, slow yellow response with GD
8	 34 Ref. 17	✓	✓	✓ ✓	✓ ✓	✓	✓ ✓	✓	Very good response with G simulant and GD, non-mutagenic

TABLE 2 (Cont'd)

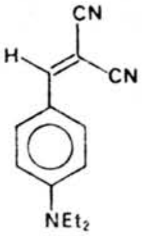
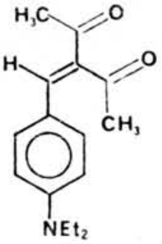
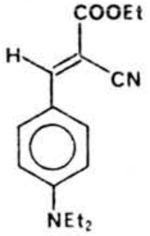
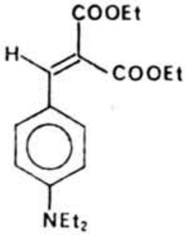
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response[b,c]	Agent Response(GD)[c]	Handsheets[d]		Mutagenicity	Comments
						Background Colour	Agent Response		
9	 35	X ✓	✓	✓	✓	X			Rejected; strong yellow background on handsheets
10	 36	X							Rejected; compound is an oil
11	 37	X ✓	✓	✓	X				Rejected; light yellow response with agent
12	 38	X							Rejected; compound is an oil

TABLE 2 (Cont'd)

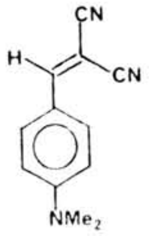
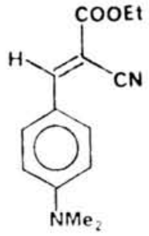
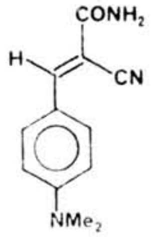
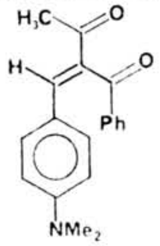
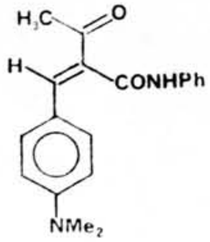
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response^{b,c}	Agent Response (GD)^{c}	Handsheets^{d}		Mutagenicity	Comments
						Background Colour	Agent Response		
13	 39 Ref. 19	✓	✓	✓	✓	X			Rejected; yellow background on handsheets
14	 40 Ref. 19	X ✓	✓	✓	X				Rejected; light yellow response with agent
15	 41 Ref. 19	✓	X	✓	X				Rejected; water soluble, no response with agent
16	 42 Ref. 19	✓	✓	X					Rejected; no response with simulant

TABLE 2 (Cont'd)

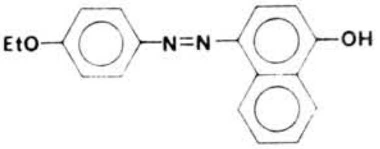
Entry No.	Structure	Melting Point	Water Solubility	Simulant Response[b,c]	Agent Response(GD)[c]	Handsheets[d] Background Colour	Agent Response	Mutagenicity	Comments
17	 43	X	✓	X					Rejected; melting point too low, slow response with simulant

[a] A check mark (✓) is used for satisfactory testing while an X indicates a failed test.

[b] The simulant for G agents is methyl cellosolve.

[c] Compounds were rubbed on filter paper for the test.

[d] Handsheets were made by incorporating the yellow dye with E (0.75%) and TBPE (1.0%).



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testing using the Ames Salmonella/mammalian microsomal mutagenicity plate incorporation assay. Results showed that PEN (34) was negative (non-mutagenic) for the five Salmonella tester strains, both in the presence and absence of metabolic activation (14).

The p-dialkylaminobenzylidene derivatives (Table 2, entries 9-17) proved to be unsatisfactory for various reasons (see Table 2). Only entries 9 and 13 possessed the proper requirements to be incorporated into handsheets. Unfortunately, both compounds gave papers with strong yellow background colours and had to be rejected for this reason.

Of the 17 candidate dyes in Table 2 only entry 8 (PEN (34)) appeared to be a promising candidate. A detailed investigation was undertaken with this dye, using the same approach described previously for Disperse Yellow 23 (vide supra). For the purpose of making handsheets, PEN was forced through a #230 mesh screen (see Experimental). Handsheets with dye loadings ranging from 0.1 to 1.2% were made and tested with 100-110 µm droplets of liquid GD. The results which are depicted in Appendix 2 (entries 3-10) showed that handsheets with dye loadings of PEN (34) of at least 0.8% gave a light yellow response when tested with 100-110 µm droplets of GD. Handsheets with 1.2% dye loading gave a quicker response but the colour produced was still light yellow. It is important to note that the current dye A2 gave inferior light yellow responses to such very small droplets. Larger drops give good yellow responses with both dyes.

Next, handsheets were prepared with E (0.75%), PEN (1.2%) and various dye loadings of TBPE (0.8 to 1.2%). The purpose was to assess the sensitivity of these handsheets towards very small droplets (100-110 µm) of agents (HD, GD and VX) and to determine the required dye loading of TBPE in order to produce the required dark green response with VX. The results of this study, presented in Appendix 2 (entries 11 to 13), showed that both the red dye E and the yellow dye PEN could detect the droplets of HD and GD with dye loadings of 0.75 and 1.2% respectively. The blue indicator dye

TBPE also could detect this droplet size of VX. A dye loading of 1.2% of TBPE was necessary to produce the required dark green response.

Analytical methods to determine the contents of the dyes in the handsheets also were developed (see Experimental section) and dye contents are reported in Appendix 2. The retention of each dye in the paper was good to excellent, and was approximately 88-95% for E, and 63-68% for TBPE, but varied considerably for PEN (35-67%).

The above results have shown that PEN is a satisfactory replacement candidate for A2. It possesses several advantages over the current dye. It is non-mutagenic and can be successfully incorporated into handsheets in the presence of E and TBPE. These handsheets can detect 100-110 μm droplets of GD. Nevertheless, the colour produced doesn't contrast as cleanly with the background colour when compared with paper made with Disperse Yellow 23. PEN can be easily synthesized by a one step reaction and can very likely be produced on an industrial scale. A one pound sample has been prepared very readily by Atlantic Chemical Corp. While PEN is not as effective as Disperse Yellow 23, it too is a viable choice to replace A2, particularly if there should be supply problems with Disperse Yellow 23. Both PEN and Disperse Yellow 23 have better sensitivity to G agents than the current mutagenic dye A2.

3.0 CONCLUSIONS

3.1 Two yellow dyes, Disperse Yellow 23 and PEN, were found to be promising replacements for A2. Both dyes are non-mutagenic and have been successfully incorporated into handsheets in the presence of E and TBPE. These handsheets give acceptable responses with droplets of the liquid CW agents, HD, GD and VX.

3.2 Disperse Yellow 23 is a commercial product and can be obtained in kilogram quantities. PEN could also readily be prepared on a commercial basis in kilogram quantities. Scale-up to cover large quantities of either dye appears feasible.

3.3 Preparation of dye material of a proper particle size for incorporation into paper and production of papers with appropriate dye content has been shown to be feasible.

3.4 Optimum dye loadings for handsheets utilizing Disperse Yellow 23 were found to be: E, 0.75%; Disperse Yellow 23, 0.6%, and TBPE, 1.0%. For handsheets utilizing PEN, these values are: E, 0.75%; PEN, 1.2%; and TBPE, 1.2%. These handsheets are able to detect droplets of HD, GD and VX as small as 100-110 µm in diameter. A stronger yellow colour is obtained with Disperse Yellow 23 than with PEN, especially with 100-110 µm droplets of GD. The G-agent responses for both these papers are significant improvements to those from the detector paper in which A2 is incorporated. This last paper cannot detect such small droplets of GD.

3.5 Disperse Yellow 23 is the current candidate of choice to replace the mutagenic dye A2. PEN also could be used. Either dye gives a better yellow response to GD than A2.

4.0 EXPERIMENTAL

4.1 General

Disperse Yellow 23 was supplied by Atlantic Chemical Corp. New Jersey, USA. TBPE was purchased from Eastman Kodak while E was supplied by Anachemia Canada Inc. The other commercial dyes were purchased from Aldrich Chemical Co. Inc. or generously supplied by Atlantic Chemical Corp. All chemicals obtained from commercial sources were used without further purification, unless noted.

Handsheets were made according to the procedure described in reference 13. Proper particle sizes of PEN, Disperse Yellow 23, TBPE and E for incorporation into paper were obtained as detailed below:

1. PEN was recrystallized from ethanol in order to agglomerate the fines. The dye was ground on a roller mill and then forced through a #250 mesh screen by spraying water. This process was done at Anachemia Canada Inc., Montreal. The concentration of the slurry obtained was 0.98% by weight. The mean mass diameter of the dye particles was 20.92 µm.

2. Disperse Yellow 23 was processed at DREO. The dye was dissolved in acetone and the solvent evaporated in order to agglomerate the fines. The solid was sifted to remove the remaining fines and ground dry through a #250 mesh screen. The mean mass diameter of the dye particles was 20.52 µm. The required amount of dye was incoporated during the process of making handsheets.

3. TBPE was ground dry through a #250 mesh screen at DREO. The mean mass diameter of the dye particles was 26.12 µm. The required amount of dye was incorporated during the process of making handsheets.

4. E was ground and screened by Anachemia Canada Inc. The mean mass diameter of the dye particles was 44.60 µm. The concentration of the slurry obtained was 21% by weight.

Analytical thin-layer chromatography (tlc) was used several times in order to follow reaction progress and to assess the purity of compounds. These analyses were performed on aluminum plates precoated with silica gel 60 (Merck F-254) using appropriate solvent systems (vide infra). Compounds were visualized by UV absorption (254 nm), immersion into a phosphomolybdic acid solution followed by heating to 200°C, or by exposure to iodine vapours. The phosphomolybdic solution was made of cerium sulfate (10 g), ammonium molybdate tetrahydrate (25 g), sulfuric acid (100 ml) and distilled water (900 ml).

Melting points were measured on a Büchi apparatus and were uncorrected. Infrared spectra were recorded on a Perkin Elmer model No. 283 instrument. High resolution ^{1}H and ^{13}C NMR spectra were obtained using a Varian XL-200 instrument. Chemical shifts are reported in ppm downfield from tetramethylsilane (TMS) and splitting patterns are designated as follows: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), b (broad), bs (broad singlet), etc. All ^{13}C spectra were proton decoupled. UV spectra were recorded on a Varian Cary 2300 spectrophotometer or a Philips Pye Unicam PU 8600 UV- Vis spectrophotometer.

4.2 Preparation of Azo Dyes

All of the azo dyes synthesized in this report were prepared according to a literature procedure (16,17). The physical data are reported below. The solvent used in recrystallizing the dyes are listed after the melting points.

phenyl-azo-salicylic acid (27): 29% yield; mp 187.5-190°C (ethanol-water, lit (21) 218°C); IR (ethyl acetate) 3400-2800, 1695, 1620, 1600, 1490, 1430 and 1225 cm^{-1}; ^{1}H NMR (acetone d-6) δ: 7.13 (d,1H,J =8.9 Hz), 7.47-7.61 (m,3H), 7.85-7.92 (m,2H), 8.12 (dd,1H,J=8.9 and 2.6 Hz), 8.48 (d,1H,J=2.6 Hz); ^{13}C NMR (acetone d-6) δ: 119.17, 123.27, 127.55, 129.65, 130.04, 131.75, 136.70, 146.01, 153.27, 165.35 and 172.38.

m-xylyl-azo-salicylic acid (28): 36% yield; mp 209-210°C (ethanol-water, lit (17) 201°C); IR (acetone) 3600, 3000, 1680, 1620, 1595, 1490, 1420, 1350, 1290, 1250-1210 and 1180 cm^{-1}; ^{1}H NMR (acetone d-6) δ: 2.84 (s,6H), 7.58 (hidden d,1H,J=8.8 Hz), 7.60 (s,1H), 7.97 (s, 2H), 8.56 (dd,1H,J=8.8 and 2.6 Hz); 8.91 (d,1H,J=2.6 Hz); ^{13}C NMR (acetone d-6) δ: 20.85, 113.14, 118.76, 120.87, 126.93, 129.30, 132.90, 139.29, 145.81, 153.19, 164.83 and 172.07.

p-ethoxyphenyl-azo-salicylic acid (29): 90% yield; mp 198-200°C (dec); IR (ethyl acetate) 3640, 3570, 1710, 1690, 1610, 1590, 1510, 1485 and 1230 cm^{-1}; ^{1}H NMR (acetone d-6) δ: 1.40 (t,3H,J=7.0 Hz), 4.15 (q,2H,J=7.0 Hz), 5.8 (bs,2H,OH), 7.07 (d,2H,AA'BB' pattern, J=9.3 Hz), 7.11 (d,1H,J=8.8 Hz), 7.88 (d,2H,AA'BB' pattern, J=9.3 Hz), 8.08 (dd,1H,J=8.8 and 2.6 Hz), 8.43 (d,1H,J=2.6 Hz); ^{13}C NMR (DMSO d-6) δ: 14.64, 63.72, 113.72, 114.98, 118.27, 124.42, 125.21, 128.75, 144.65, 146.00, 161.08, 163.13 and 171.58.

m-xylyl-azo-α-hydroxynaphthoic acid (33): 53% yield; mp 192-193°C (ethanol-water, lit (17) 180°C); IR (DMSO) 3500, 1660, 1635, 1590, 1510 and 1250 cm^{-1}; ^{1}H NMR (acetone d-6) δ: 2.43 (s,6H), 7.20 (bs,1H), 7.67 (bs,2H), 7.76 (t,1H,J=8 Hz), 7.88 (t,1H,J=8 Hz), 8.33 (s,1H), 8.47 (d,1H,J=8.3 Hz), 8.98 (d,1H,J=8.3 Hz); ^{13}C NMR (acetone d-6) δ: 21.08, 106.42, 111.64, 120.52, 123.10, 123.63, 124.67, 126.86, 130.70, 132.58, 134.61, 138.92, 152.64, 163.27 and 173.10.

p-ethoxyphenyl-azo-α-hydroxynaphthoic acid (34) (PEN): 59% yield; mp 183-184°C (ethanol-water, lit (17) 198.5°C); IR (DMSO) 3600-3400, 1670, 1635, 1610, 1590, 1510, 1260-1250 and 1150 cm^{-1}; ^{1}H NMR (DMSO d-6) δ: 1.30 (t,3H,J=7.0 Hz), 4.04 (q,2H,J=7.0 Hz), 7.02 and 7.89 (2d,4H,AA'BB' pattern, J=8.9 Hz), 7.63 (t,1H,J=9 Hz), 7.78 (t,1H,J=9 Hz), 8.06 (s,1H), 8.30 (d,1H,J=8.2 Hz), 8.78 (d,1H,J=8.2 Hz); ^{13}C NMR (DMSO d-6) δ: 14.80, 63.85, 106.23, 110.91, 115.05, 123.14, 123.57, 124.60, 124.79, 126.75, 130.49, 134.54, 139.04, 146.87, 161.18, 162.54 and 173.30; UV (chloroform) 384 nm (24,000).

Since Disperse Yellow 23 was found to be the best replacement for A2 (2), we report similar data below, even though it is a commercially available dye.

Disperse Yellow 23 (20): mp 180-182°C; IR (DMSO) 3480, 1600, 1290 and 1150 cm^{-1}; ^{1}H NMR (DMSO d-6) δ: 6.96 (d,2H,J=8.7 Hz), 7.58 (m,3H), 7.83-8.07 (m,8H), 10.46 (bs,1H); ^{13}C NMR (DMSO d-6) δ: 116.39, 122.98, 123.53, 124.02, 125.57, 129.78, 132.12, 145.78, 152.22, 152.71, 153.67 and 161.75; UV (1% aqueous sodium hydroxide) 480 nm (32,000).

4.3 Preparation of p-dialkylaminobenzylidene Derivatives of Active Methylene Compounds

The p-dialkylaminobenzylidene derivatives of active methylene compounds were prepared by condensation of p-dialkylaminobenzaldehydes with malononitrile and other compounds having an active methylene group. Two procedures (A and B) were used and are described below. Compounds 36 to 38 were prepared according to procedure A while compounds 35 and 39-43 were prepared according to procedure B. Physical data for each compound are given below along with reaction conditions.

Procedure A

To a solution of p-dialkylaminobenzaldehyde (14.1 mmol) and the active methylene compound (14.1 mmol) in benzene (30-50 mL) was added 1 mL of the catalyst solution (1 mL of piperidine, 3 mL of acetic acid and sufficient benzene to give a volume of 10 mL) and the mixture was heated to reflux. At the end of the reaction (see details below), the solvent was removed and the residue dissolved in ethyl acetate (50 mL). The solution was washed with an aqueous saturated solution of sodium bicarbonate and finally with brine. It was then dried over anhydrous magnesium sulfate, filtered and solvent removed. The resultant crude product was purified by recrystallization or by trituration with the appropriate solvent (vide infra).

Procedure B

To a solution of p-dialkylaminobenzaldehyde (16.8 mmol) and the active methylene compound (16.8 mmol) in absolute ethanol (30-50 mL) was added 1 mL of the catalyst solution (consisting of 1 mL of piperidine, 3 mL of acetic acid and sufficient absolute ethanol to give a volume of 10 mL) and the mixture heated to reflux. After the reaction was completed (see details below), the mixture was cooled to 0°C, the solid formed collected by filtration, washed with cold absolute ethanol and air dried.

3-(p-diethylaminobenzylidene)-malononitrile (35) (procedure B): The reaction was followed by tlc using ethyl acetate-hexane (3:7) as eluent. After 2h, the reaction was stopped, cooled to 0°C and the red solid collected by filtration in 89% yield: mp 129-131°C; IR ($CHCl_3$) 2995, 2230, 1620, 1570, 1525, 1425, 1360, 1285, 1200, 1165 and 1080 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.23 (t,6H,J=7.4 Hz), 3.47 (q,4H,J=7.4 Hz), 6.66 and 7.78 (2d,4H,AA'BB' pattern, J=8.9 Hz), 7.41 (s,1H).

3-(*p*-diethylaminobenzylidene)-acetylacetone (36) (procedure A): The reaction progress was followed by tlc using ethyl acetate-hexane (3:7) as eluent. After 8h, the reaction was stopped and the product isolated as previously described. The desired compound was obtained as a red oil in 73% yield: IR (neat) 2980, 1710, 1650, 1600-1580, 1530, 1410, 1360, 1325, 1280, 1200, 1160 and 1010 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.17 (t,6H,J=7.0 Hz), 2.35 (s,6H), 3.38 (q,4H,J=7.0 Hz), 6.59 and 7.25 (2d,4H,AA'BB' pattern, J=8.8 Hz), 7.34 (s,1H).

3-(*p*-diethylaminobenzylidene)-ethyl cyanoacetate (37) (procedure A): The reaction progress was followed by tlc using ethyl acetate-hexane (1:4) as eluent. After 4h, the reaction was stopped and the product isolated as described previously. The crude product (red oil) was triturated in hexane to allow crystallization, filtered and air dried. The yellow powder was obtained in 66% yield: mp 92-93°C; IR ($CHCl_3$) 3020, 2990, 2220, 1715, 1620, 1575, 1525, 1420, 1360, 1280, 1235, 1190, 1160, 1100, 1080 and 1010 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.21 (t,6H,J=7.0 Hz), 1.36 (t,3H,J=7.0 Hz), 3.44 (q,4H,J=7.0 Hz), 4.32 (q,2H,J=7.0 Hz), 6.66 and 7.90 (2d,4H,AA'BB' pattern, J = 8.6 Hz), 8.03 (s,1H).

3-(*p*-diethylaminobenzylidene)-diethylmalonate (38) (procedure A): The reaction progress was followed by tlc using ethyl acetate-hexane (1:9) as eluent. The reaction was completed after 9h and the product isolated as described previously. The compound was obtained as a red oil in 96% yield: IR (neat) 2990, 1735-1705, 1600, 1530, 1275, 1225, 1185, 1160 and 1070 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.17 (t,6H,J=7.0 Hz), 1.33 and 1.30 (2t,6H,J=7.0 Hz), 3.38 (q,4H,J=7.0 Hz), 4.38 and 4.26 (2q,4H,J=7.0 Hz), 6.58 and 7.33 (2d,4H,AA'BB' pattern, J=8.8 Hz), 7.59 (s,1H).

3-(*p*-dimethylaminobenzylidene)-malononitrile (39) (procedure B): The reaction progress was followed by tlc using ethyl acetate-hexane (3:7) as eluent. After 2h of refluxing, the reaction was stopped, cooled to 0°C and the orange solid collected by filtration and air dried. The solid was obtained in 90% yield: mp 179-180°C (lit(19) 178-179°C); IR ($CHCl_3$) 3030, 2930, 2225, 1620, 1570, 1530, 1450, 1390, 1370, 1200 and 1180 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 3.13 (s,6H), 6.67 and 7.79 (2d,4H, AA'BB' pattern, J=9.2 Hz), 7.43 (s,1H).

3-(*p*-dimethylaminobenzylidene)-ethyl cyanoacetate (40) (procedure B): The reaction mixture was heated to reflux for 4h and left overnight at room temperature. The yellow solid formed in the reaction mixture was collected by filtration in 81% yield: mp 123-125°C (lit(19) 127-128 °C); IR ($CHCl_3$) 3020, 2220, 1715, 1620, 1580, 1535, 1450, 1385, 1370, 1335, 1285, 1235, 1190, 1175 and 1095 cm^{-1}; ^1H NMR ($CDCl_3$) δ: 1.36 (t,3H,J=7.4 Hz), 3.09 (s,6H), 4.32 (q,2H,J=7.4 Hz), 6.67 and 7.91 (2d,4H,AA'BB' pattern, J=9.3 Hz)' 8.05 (s,1H).

3-(*p*-dimethylaminobenzylidene)-cyanoacetamide (41) (procedure B): The reaction progress was followed by tlc using ethyl acetate-hexane (1:1) as eluent. The reaction was stopped after 2.5h, cooled to 0°C and the orange solid collected by filtration in 78% yield: mp 192-194°C (lit (19) 194-195°C); IR (DMSO) 3350, 3180, 2210, 1685, 1615, 1590-1565, 1530, 1370, 1200 and 1180 cm^{-1}; ^{1}H NMR (acetone d-6) δ: 3.11 (s,6H), 6.82 and 7.91 (2d,4H,AA'BB' pattern, J=9.0 Hz), 8.04 (s,1H).

3-(p-dimethylaminobenzylidene)-benzoylacetone (42) (procedure B): The reaction progress was followed by tlc using ethyl acetate-hexane (3:7) as eluent. The mixture was refluxed for 18h, cooled to 0°C and the orange-yellow solid collected by filtration in 25% yield: mp 180-182 °C (lit(19) 182-184°C); IR ($CHCl_3$) 3020, 1680, 1595, 1530, 1375, 1330, 1230, 1215, 1195 and 1170 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ: 2.34 (s,3H), 2.93 (s,6H), 6.47 and 7.96 (2d,4H,AA'BB' pattern, J=9.0 Hz), 7.20-7.53 (m,5H), 7.70 (s,1H).

3-(p-dimethylaminobenzylidene)-acetoacetanilide (43) (procedure B): The reaction progress was followed by tlc using ethyl acetate-hexane (1:1) as eluent. The reaction mixture was heated to reflux for 5h and then stirred at room temperature for 2 days. The mixture was filtered and the filtrate treated with hexane to allow precipitation of a yellow-orange solid. This solid was collected by filtration in 44% yield: mp 78-82°C; IR (DMSO) 1690, 1660, 1620, 1540, 1210 and 1185 cm^{-1}: ^{1}H NMR (acetone d-6) δ: 2.33 (s,3H), 2.99 (s,6H), 6.67 and 7.76 (2d,4H,AA'BB' pattern, J=9.5 Hz), 7.09-7.55 (m,5H), 9.45 (bs,1H).

4.4 Procedures for the Determination of the Dye Content of E, Disperse Yellow 23, and TBPE in 3-Way Detector Paper

In order to determine the content of each individual dye in the paper, the dyes were extracted from the paper using either an organic solvent or an aquous solution. The extracts were diluted to make a stock solution and the absorbance of each solution was measured using a UV-Vis spectrophotometer against the appropriate blank. The dye content was calculated from the absorbance of each solution using the mathematical equations shown below.

The dyes were extracted from the paper as follows: Two 5 x 10 cm pieces of paper to be tested were weighed precisely. One piece was cut into 8-10 smaller strips and extracted in a test tube with several 10-15 mL portions of chloroform until the extracts were colourless. The extracts were transferred into a 250 mL volumetric flask and the flask was filled to the mark with chloroform (solution A). This solution contained all three dyes and the absorbance of E was measured directly from it. There was no interference from the other two dyes.

A 10.00 mL aliquot of solution A was treated with 1.00 mL of diethylamine and 20.00 mL of acetone. This mixture was transferred into a 50 mL volumetric flask and diluted with chloroform (solution B). The addition of diethylamine and acetone changes TBPE to its basic form and causes a bathochromic shift of its λ max to an area of the spectrum where no interference exists. From the absorbance the dye content of TBPE in the paper was calculated (see below).

The second piece of paper was cut into 8-10 small pieces and extracted with 150 mL of boiling 1% aqueous sodium hydroxide until no trace of blue or green colour could be detected in the solution. The extracts were cooled to room temperature, transferred into a 250 mL volumetric flask and diluted with 1% aqueous sodium hydroxide (solution C). This process extracted both Disperse Yellow 23 and TBPE as their basic forms and left E in the paper. The treatment with base also caused the saponification of TBPE and its further transformation into 3',3",5',5"-tetrabromophenolphthalein. Since this last compound has its λ max in the UV region, the absorbance of Disperse Yellow 23 could be measured without interference.

The dye contents of the dyes in the paper were calculated by measuring the absorbance of each individual solution of dye. The mathematical equations used are shown below.

The dye content is the percentage of the weight of dye incorporated into the paper relative to the total weight of the paper sample (Eq. 1):

$$\text{dye content (\%)} = \frac{\text{weight of dye}}{\text{weight of paper sample}} \times 100\% \qquad \text{Eq. 1}$$

The weight of a particular dye in solution can be determined using Eq. 2:

$$\text{weight of dye} = c \times \text{m.w.} \times v \qquad \text{Eq. 2}$$

where c = molar concentration of the solution
m.w. = molecular weight of the dye
v = volume of the stock solution

The concentration c can then be determined using the Beer-Lambert law, i.e.:

$$A_\lambda = \varepsilon bc$$

where ε = molar absorptivity
b = path length of the cell (1 cm)
A_λ = absorbance at a particular wavelength (λ)

Since b = 1 cm, the Beer-Lambert law can be simplified to:

$$c = A_\lambda/\varepsilon \qquad \text{Eq. 3}$$

The value of ε was obtained for each dye used in the paper making from a plot of A_λ versus c using a series of standard solutions of known dye concentration. Substituting equation 3 into 2 and then 2 into 1 gives:

$$\text{dye content (\%)} = \frac{A_\lambda \times \text{m.w.} \times v/\varepsilon}{\text{weight of paper sample}} \times 100\% \qquad \text{Eq. 4}$$

If a dilution factor (df) has to be taken into account (e.g. for TBPE), the final equation can be written as:

$$\text{dye content (\%)} = \frac{(A_\lambda \times \text{m.w.} \times v \times \text{df})/\varepsilon}{\text{weight of paper sample}} \times 100\% \qquad \text{Eq. 5}$$

or simply

$$\text{dye content (\%)} = \frac{K \times A_\lambda}{\text{sample weight}} \qquad \text{Eq. 6}$$

$$\text{with } K = \frac{\text{m.w.} \times v \times \text{df} \times 100\%}{\varepsilon}$$

The absorbance of dye E is measured from solution A against a chloroform blank, the absorbance of dye TBPE is measured from solution B against a blank of 2% diethylamine, 40% acetone and 58% chloroform while the absorbance of dye D.Y. 23 is measured from solution C against a blank of 1% aqueous solution hydroxide. The figures for each dye are shown below.

	E	TBPE	Disperse Yellow 23
λ max (nm)	554	611	480
ε	47,100	92,200	32,000
m.w. (g)	881	662	302
v (L)	0.250	0.250	0.250
df	1	5	1
K	0.467	0.897	0.236

4.5 Procedures for the Determination of the Dye Content of E, PEN and TBPE in 3-Way Detector Paper

The procedure for the determination of the dye contents of E and TBPE was identical to those described in Section 4.4. To determine the dye content of PEN, the following procedure was used.

The second piece of paper was cut into 8-10 small pieces and extracted with 150 mL of boiling 1% aqueous sodium carbonate until the solution turned orange. The extract was cooled to room temperature, transferred into a 250 mL volumetric flask and filled to the mark with 1% aqueous sodium carbonate (solution C). The absorbance of PEN was measured against a blank of 1% aqueous sodium carbonate. The dye content was determined using Eq. 6 and the following values:

λ max (nm) = 490
ε = 12,400
m.w. (g) = 336
v (L) = 0.250
df = 1
K = 0.677

5.0 ACKNOWLEDGEMENTS

The authors are grateful to Dr. J.J. Janacek, vice president of Anachemia Canada Inc., to Dr. J.J. Norman of DREO and to Dr. B.B. Bochner of Atlantic Chemical Corp. New Jersey, USA for their help throughout this project. The work on this project (as described in this report and references 12 and 13) was carried out jointly by DREO and Anachemia personnel (DSS contract 14SV.97714-4-2608). Majors P.G. Pothier and C.J. Thorp of DCGEM-5 are thanked for their assistance in arranging funding for this project and for discussions on military aspects of detection.

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APPENDIX 1

Properties of Handsheets made with E, Disperse Yellow 23 and TBPE

Entry No.	Handsheets No.	Dye(s)	Dye loading (%)	Dye Content(%) (retention(%))	Background colour	Simulant response	Agent response	Droplets*
1	1529	E	0.75	-	light brown	red	red	(a)
		D.Y. 23	0.2	-		green	yellow	
		TBPE	1.0	-		dark blue	dark green	
2	1530	E	0.75	-	brown	red	red	(a)
		D.Y. 23	1.0	-		green	orange	
		TBPE	1.0	-		dark blue	dark green	
3	1603	D.Y. 23	0.2	-	white	light yellow	light yellow	(b)
4	1604	D.Y. 23	0.4	-	white	dark yellow	yellow	(b)
5	1605	D.Y. 23	0.6	-	off-white	orange/yellow	yellow	(b)
6	1606	D.Y. 23	0.8	-	v.light brown	orange	yellow	(b)
7	1613	E	0.75	-	greenish grey	red	red	(b)
		D.Y. 23	0.6	-		green	yellow	
		TBPE	1.2	-		v.dark blue	v.dark green	
8	1614	E	0.75	-	grey	red	red	(b)
		D.Y. 23	0.6	-		green	yellow	
		TBPE	1.0	-		v.dark green	v.dark green	
9	1608	E	0.75	0.7 (93%)	light grey	red	red	(b)
		D.Y. 23	0.6	0.39 (65%)		green	yellow	
		TBPE	0.8	0.5 (60%)		dark blue	dark green	
10	1609	E	0.75	0.64 (85%)	light grey	red	red	(b)
		D.Y. 23	0.6	0.29 (48%)		green	yellow	
		TBPE	0.6	0.38 (63%)		dark blue	green	
11	1610	E	0.75	0.62 (82%)	light grey	red	red	(b)
		D.Y. 23	0.6	0.34 (56%)		green	yellow	
		TBPE	0.4	0.27 (67%)		blue-green	light green	
12	1611	E	0.75	0.72 (96%)	light grey	red	red	(b)
		D.Y. 23	0.6	0.4 (67%)		yellow	yellow	
		TBPE	0.2	0.15 (75%)		green	yellow	

* For entries designated with "(a)", agent droplet sizes were not measured but, for entries designated with "(b)", agent droplets having diameters of 100-110 µm were used. See Ref. 15 for the equipment and procedure used to produce these agent droplets.

APPENDIX 2

Properties of Handsheets made with E, PEN and TBPE

Entry No.	Handsheets No.	Dye(s)	Dye loading (%)	Dye Content(%) (retention(%))	Background colour	Simulant response	Agent response	Droplets*
1	1518	E PEN TBPE	0.75 0.10 1.0	- - -	beige	red green dark blue	red yellow dark green	(a)
2	1519	E PEN TBPE	0.75 0.8 1.0	- - -	beige	red green dark blue	red dark yellow dark green	(a)
3	1593	PEN	0.1	-	light tan	light yellow	no response	(b)
4	1596	PEN	0.2	.086 (43%)	light tan	light yellow	no response	(b)
5	1594	PEN	0.3	-	light tan	yellow	no response	(b)
6	1595	PEN	0.5	.29 (58%)	light brown	yellow	v.light yellow	(b)
7	1597	PEN	0.6	.29 (48%)	light brown	yellow	v.light yellow	(b)
8	1598	PEN	0.8	.42 (52%)	light brown	yellow	light yellow	(b)
9	1599	PEN	1.0	.53 (53%)	light brown	yellow	light yellow	(b)
10	1602	PEN	1.2	-	light brown	dark yellow	light yellow	(b)
11	1615	E PEN TBPE	0.75 1.2 0.8	.70 (93%) .42 (35%) .54 (68%)	light brown	red green dk.blue-green	red v.light yellow green	(b)
12	1616	E PEN TBPE	0.75 1.2 1.0	0.71 (95%) .53 (44%) .64 (64%)	brown	red green dk.blue-green	red light yellow green	(b)
13	1617	E PEN TBPE	0.75 1.2 1.2	0.71 (95%) 0.81 (67%) 0.75 (63%)	brown	red green dark blue	red light yellow dark green	(b)

* For entries designated with "(a)", agent droplet sizes were not measured but, for entries designated with "(b)", agent droplets having diameters of 100-110 µm were used. See Ref. 15 for the equipment and procedure used to produce these agent droplets.

APPENDIX 2

Properties of Handsheets made with E, PEN and TBPE

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3	1593	PEN	0.1	-	light tan	light yellow	no response	(b)
4	1596	PEN	0.2	.086 (43%)	light tan	light yellow	no response	(b)
5	1594	PEN	0.3	-	light tan	yellow	no response	(b)
6	1595	PEN	0.5	.29 (58%)	light brown	yellow	v.light yellow	(b)
7	1597	PEN	0.6	.29 (48%)	light brown	yellow	v.light yellow	(b)
8	1598	PEN	0.8	.42 (52%)	light brown	yellow	light yellow	(b)
9	1599	PEN	1.0	.53 (53%)	light brown	yellow	light yellow	(b)
10	1602	PEN	1.2	-	light brown	dark yellow	light yellow	(b)
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* For entries designated with "(a)", agent droplet sizes were not measured but, for entries designated with "(b)", agent droplets having diameters of 100-110 µm were used. See Ref. 15 for the equipment and procedure used to produce these agent droplets.

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(U) The Paper, Chemical Agent Detector, 3-Way Liquid is used by the Canadian Forces for the detection of liquid chemical warfare agents and is supplied by Canada to many Western countries. Unfortunately, two of the three dyes used in the detector paper have been found to be mutagenic and thus a project was initiated to find non-mutagenic replacement dyes. This report describes the work leading to the replacement of dyestuff A2, which is currently used to detect G-type nerve agent liquid droplets. Candidate replacement dyes were either procured commercially or synthesized when not available commercially. Two good, non-mutagenic, replacement dyes for A2 have been found, namely Disperse Yellow 23 and p-ethoxyphenyl-azo-α-hydroxynaphthoic acid. These dyes were incorporated into paper, both alone and in the presence of the dyes used for detection of mustard and V-type nerve agents. Various dye loadings were used. Based on the results obtained, Disperse Yellow 23 was recommended as the replacement for the current dye A2. This dye gave brighter yellow responses than A2 and the other candidate replacement dye. Detector paper made with this dye is capable of detecting smaller droplets of G-type nerve agents.(U)

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