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Assessment of inward leakage tests for air fed suits

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Assessment of inward leakage tests for air fed suits

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This report describes work carried out as part of an inter-laboratory round-robin exercise to investigate the practicality and usefulness of a simultaneous multi-point in-suit sampling protocol for the assessment of inward leakage into air fed suits proposed for the revision of the relevant European Standard. HSL had concerns that this revised protocol would not produce the optimum level of information on suit performance, and would limit the highest levels of protection that could be measured.

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EXECUTIVE SUMMARY

Objectives

This report describes work carried out as part of an inter-laboratory round-robin exercise to investigate the practicality and usefulness of a simultaneous multi-point in-suit sampling protocol for the assessment of inward leakage into air fed suits proposed for the revision of the relevant European Standard. HSL had concerns that this revised protocol would not produce the optimum level of information on suit performance, and would limit the highest levels of protection that could be measured.

Main Findings

While it is practically possible to make in-suit measurements of inward leakage using the simultaneous multi-point sample technique, results obtained using this approach do not agree well with the mean value of separate sequential samples drawn from the same suit locations, where appreciable levels of inward leakage are present. The combination of several samples before analysis has the effect of masking single high values. Individual sequential samples give the greatest resolution and contrast in suit assessment and hence the most rigorous performance measurement.

Common pass/fail criteria cannot be applied to both single samples and multi-point simultaneous samples if consistent levels of protection are to be applied throughout the suit. The pass/fail criterion for simultaneous samples must be reduced by a factor of the number of points sampled if consistent levels of protection are to be ensured. Using this reduced pass/fail criterion also has the consequence of the possibility of false failures under some conditions of inward leakage. Levels of inward leakage that require to be measured to assess the highest performing class of suit would also be reduced below the detection limits commonly achievable in the participating test laboratories.

Applying a single pass/fail criterion throughout the suit where a mixture of single and simultaneous samples is used for assessment would accept the concept of different levels of protection in the sampled regions. Consideration from radiological / toxicological protection stances would be necessary before this approach could be adopted.

Walking and squatting exercises proved to be the most likely to induce suit leakage. The suits tested did not maintain positive pressure during the test exercises.

Recommendation

Assessment of inward leakage into air fed suits would benefit from introduction of a multi-point sampling procedure. A protocol of sequential sampling from three suit locations (rather than combining samples from the three locations before analysis) during a test exercise sequence involving only walking and squatting is suggested.

1 INTRODUCTION

European Standards committee TC162 / WG3 is revising the standards relating to suits for protection against radioactive particulate material:

- EN 1073-1 ventilated suits
- EN 1073-2 non-ventilated suits
- Possible introduction of EN 1073-3 for suits incorporating a powered filtering device

Within this revision, the standard method for assessing the leakage of airborne particles into the suit has come under scrutiny. In the existing versions of these standards, this is only assessed using a single sampling position at the region immediately in front of the nose/mouth of a test subject wearing the suit while they undertake defined exercises in a challenge atmosphere. This has been recognised as less than adequate to assess the performance of suits that are intended to prevent contamination to the body as well as to protect the respiratory system. More recent related standards (EN 13982-1 and –2) require sequential sampling from at least three locations within a suit.

Multiple sampling points have therefore been proposed to improve the assessment of protection against radioactive particles. However, the question of whether these sampling points can be assessed simultaneously rather than sequentially has been posed. Simultaneous sampling would significantly reduce the time required for testing, reduce the burden on test subjects, and limit the costs associated with the test. However, the theoretical and practical implications of such testing have not been evaluated. A Task Group was set up to carry out a round-robin test exercise to investigate these points, with laboratories in France (IRSN), Germany (IFT) and UK (HSL) participating. The work reported here describes HSL's input to this round-robin testing exercise.

HSL has concerns over the proposed simultaneous multi-point sampling procedure due to the potential lowering of the resolution of the smallest leak into a suit that can be detected, and degradation of the quality of information on leak site location that would otherwise be possible with sequential samples. For this reason we undertook to sample from suits following both the simultaneous (round-robin) scheme, and a sequential scheme.

Testing activity using human subjects for this work was conducted under the generic PPE Ethics Committee approval ETHCOM/REG/08/07.

2 TEST METHODS

2.1 ROUND-ROBIN SIMULTANEOUS MULTI-POINT SAMPLING

The procedure developed within the Task Group (see Appendix A) was used to assess suit simultaneous multi-point inward leakage. This draws air simultaneously from four locations within the suit and combines them into a single mixed sample before they pass to the analysis system for continuous concentration monitoring. HSL used a four-point simultaneous scheme, with sampling locations in the right leg, chest, left arm and immediate breathing zone of the suit. These four sampling locations were connected to a purpose-made manifold/pass-through (Figure 1) using identical lengths of sampling tube. In this way, the individual sampling flow rates were equalised, minimising any sampling bias.

Sampling lines in the body area of the suit were terminated in rectangular multi hole blocks, as described in Appendix A. The breathing zone sampling line was terminated in a standard ball probe.

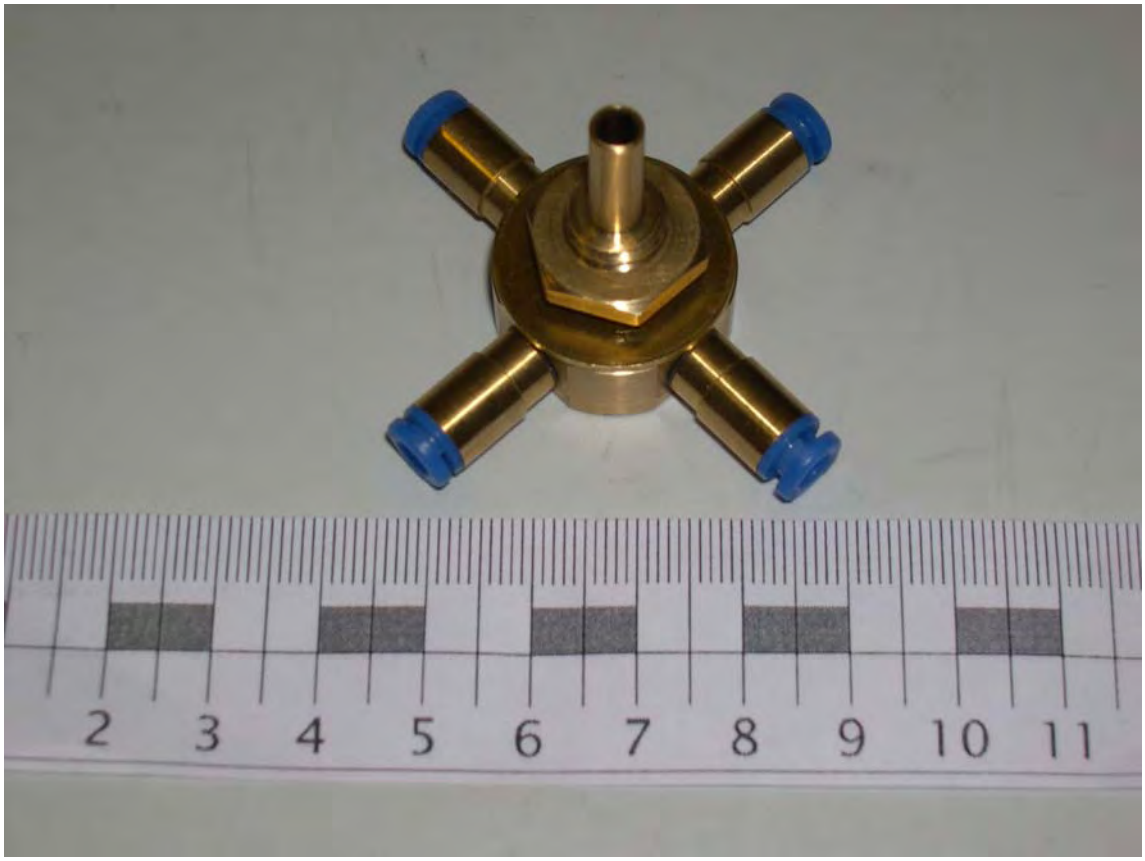


Figure 1. Multi-point simultaneous sample manifold/pass-through.

2.2 SEQUENTIAL MULTI-POINT SAMPLING

The suit sampling procedure contained in EN 13982-2 was used, with three suit locations being sampled and assessed separately in sequence: leg, chest and breathing zone. Sampling lines in

the leg and chest area of the suit were terminated in rectangular multi hole blocks, as described in Appendix A. The breathing zone sampling line was terminated in a standard ball probe.

2.3 EXERCISE PROTOCOL

Two test subjects each wore two suits of an appropriate size. Air flow to the suits was set at the manufacturer's stated minimum flow rate. The test exercise protocol was as described in Table 1, with each complete test lasting approximately 90 minutes.

Table 1. Test exercise protocol used

Activity	Duration (approx. minutes)
Don suit	5
Enter chamber and connect to sampling system	2
Sampling while standing still, no test agent (man-zero measurement)	3 per sampling line (4 lines in total)
Introduce test agent	5
1. Standing still, with test agent	3 per sampling line (4 lines in total)
2. Walking 5 km/hr	3 per sampling line (4 lines in total)
3. Standing, moving object between desk top height and shelf at eye level with both arms	3 per sampling line (4 lines in total)
4. Standing / squatting 5 times/min	3 per sampling line (4 lines in total)
Stop test agent and purge chamber	10
Disconnect from sampling lines and doff suit	5
Total session time	~90

Our inward leakage measurement system has a detection limit of 0.001% under the conditions used in these tests. The sampling sequence used for each test exercise was HEAD – BODY – LEG – 4 POINT SAMPLE.

2.4 INFORMATION RECORDED / CALCULATED

The following parameters were recorded during the tests.

- Continuous monitoring and chart-recording of in-suit pressure relative to that in the test chamber, to assess a proposed standard requirement that in-suit pressure must remain higher than ambient at all times during the test exercises.

- Continuous recording of the inward leakage of test agent into the suit, calculated by subtracting the relevant man-zero value for each sampling line from the measurement made during a given exercise from that line, and dividing by the challenge concentration.

Based on the continuous measurements of leakage, the following parameters were derived:

1. Calculation of the inward leakage measured by the simultaneous sample technique for each exercise, averaged for a given suit type and test subject.

2. Calculation of the overall inward leakage measured by the simultaneous sample technique for each suit type. (i.e. the mean inward leakage for a given suit type over both subjects, and all exercises.)

3. Calculation of the individual exercise inward leakages for a given suit type measured from sequential samples, averaged for each wearer and exercise.

4. Calculation of the overall inward leakage for a given suit type measured from sequential samples. (i.e. the mean inward leakage for a given suit type over both subjects, all sampling locations, and all exercises.)

Results were then compared with the existing EN 1073-1 inward leakage requirements, which are summarised in Table 2.

Table 2. EN 1073-1 inward leakage requirements

Class	Maximum value of mean inward leakage during exercise of	
	One activity (%)	All activities (%)
5	0.004	0.002
4	0.01	0.005
3	0.02	0.01
2	0.04	0.02
1	0.10	0.05
Note 1. Maximum value is calculated as the average performance over all test sequences.		

3 SUITS TESTED

3.1 GENERAL

Four samples of each of two types of suit were supplied for this work through the convenor of the Task Group, with two each of sizes Large and X-Large for each suit type.

3.2 SUIT A

This is a one-piece welded plastics suit, having welded-on gloves and integral bootees, and vertical double-zipped rear entry (see Figure 2). Breathable compressed air is supplied via a manually controlled flow valve to the right hip and a front-mounted quick-release connector. Internally, the air is distributed to the ends of the arms and legs only, with two large exhaust valves situated one each in the rear head and mid back regions of the suit. There is no internal compartmentalisation within the suit. The minimum flow specified for the suit by the manufacturer is 450 L/min, which was established using a supply pressure of 3.2 bar with the manual flow control in the fully open position. The suit is intended for single use only.

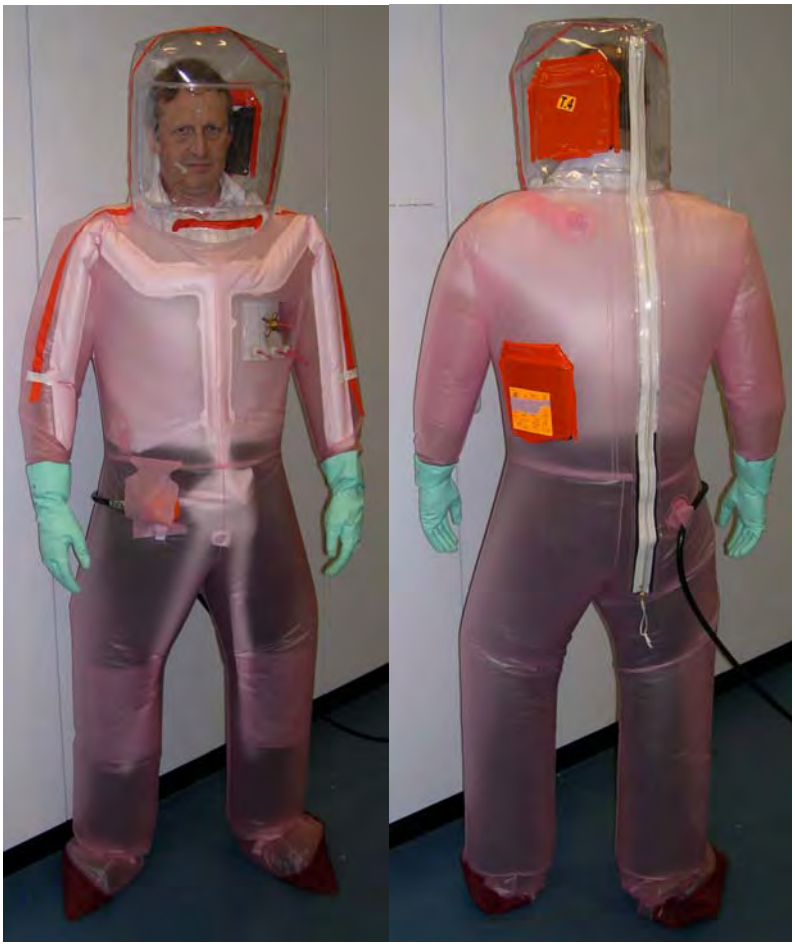


Figure 2. Front and rear view of Suit A

3.3 SUIT B

This is a one-piece suit constructed from a coated non-woven polypropylene fabric using over-taped seams (see Figure 3). Integral bootees were provided, but gloves required to be attached using a rigid cuff and o-ring system. The suit has a horizontal front-entry double zip opening, nominally covered with a double over-flap with adhesive tape fastening. The suit is intended for single use, and was originally designed to be used in conjunction with a powered filtering respirator system instead of a compressed air line – suitable adapters to convert the supply to compressed breathable air were provided for the purposes of these tests. The manufacturer's stated minimum air flow of 120 L/min was used, being achieved at a supply pressure of 0.7 bar. Air supply is entirely into the hood region of the suit, which is partially segregated from the rest of the suit by an elasticated neck dam. There are two exhaust valves from the suit, one each to the hood rear and lower back regions.

For the purposes of these tests we deliberately did not seal over the front zip fastening using the adhesive tape strips provided. (See section 5.1.)

Figure 3. Front and rear view of Suit B

3.4 TEST SUBJECTS

The same two test subjects were used for all tests, as follows:

Gender	M	M
Age	55	53
Height (cm)	183	180
Weight (kg)	79	89
Suit size used	L	XL

Subjects were passed as medically fit to undertake these exercises, in accordance with the generic Ethics Committee approval.

4 TEST RESULTS

4.1 SIMULTANEOUS SAMPLES

Results from the 4-point simultaneous inward leakage measurements on the two designs of suit are shown in Tables 3 and 4. Mean values in bold type were compared with the pass/fail criteria in Table 2.

Table 3. Inward leakage results from simultaneous 4-point sampling of Suit A

Exercise	Inward leakage (%)				Mean for exercise	Standard deviation
	Test subject 1		Test subject 2			
	Suit 1	Suit 2	Suit 3	Suit 4		
Standing	<0.001*	<0.001*	<0.001*	<0.001*	**<0.001**	>0
Walking 5 km/hr	<0.001*	<0.001*	<0.001*	<0.001*	**<0.001**	>0
Moving object table to shelf	0.001	<0.001*	<0.001*	<0.001*	**<0.001**	>0
Squatting 5/min	<0.001*	0.004	0.004	0.002	**<0.003**	>0.002
Mean	<0.001	<0.002	<0.002	<0.001	**Overall suit mean <0.001**	
Standard deviation	>0	>0.002	>0.002	>0.001	Overall suit SD >0.001	
* for the purposes of calculation, these values are treated as 0.001, but the consequences of the inequalities are considered in the stated results for means and standard deviations.						

Suit A would be classified according to Table 2 as Class 5.

Table 4. Inward leakage results from simultaneous 4-point sampling of Suit B

Exercise	Inward leakage (%)				Mean for exercise	Standard deviation
	Test subject 1		Test subject 2			
	Suit 1	Suit 2	Suit 3	Suit 4		
Standing	<0.001*	0.001	<0.001*	0.003	**<0.002**	>0.001
Walking 5 km/hr	0.002	0.004	0.003	0.009	**0.005**	0.003
Moving object table to shelf	0.002	0.001	0.002	0.003	**0.002**	0.001
Squatting 5/min	0.006	0.053	0.069	0.122	**0.063**	0.048
Mean for suit	<.003	0.015	0.019	0.034	**Overall suit mean <0.018**	
Standard deviation	>0.002	0.025	>0.034	0.059	Overall suit SD >0.034	
* for the purposes of calculation, these values are treated as 0.001, but the consequences of the inequalities are considered in the stated results for means and standard deviations.						

Suit B would be classified according to Table 2 as Class 1.

4.2 SEQUENTIAL SAMPLES

Results from the individual sequential 3-point inward leakage measurements on the two designs of suit are shown in Tables 5 and 6. Mean values in bold type were compared with the pass/fail criteria in Table 2.

Suit A would be classified according to Table 2 as just falling within the Class 5 requirement.

Suit B, with its unsealed zip closure configuration, would fail to achieve the minimum requirement for Class 1.

4.3 IN-SUIT PRESSURE

Suit A was pressure probed in the body region; suit B was pressure probed in the hood region.

For both suits, all tests show that the in-suit pressure can fall below surrounding ambient pressure. This was most pronounced during the walking exercise for suit B, and during squatting for suit A. Suit B gave greater negative pressures than Suit A.

The squatting procedure we used was to crouch down slowly and smoothly over a 6 second period, and to rise again slowly and smoothly, extending the arms, over another 6 second period, and repeat.

4.4 DAMAGE TO SUITS DURING TESTS

During both squatting exercises with the X-Large Suit A samples, the internal air distribution system burst - crouching down had folded and closed off all four outlets of the distribution spider at the arms and legs. This did not compromise the integrity of the outer barrier layer of the suit or reduce the airflow to the wearer, so testing was continued.

Following testing of Suit A, subject 1, suit 1, a small (2 x 3 mm) hole was noticed in the outer suit material adjacent to the position of the hose coupling. This appears to have had no discernable effect on measured inward leakages.

Table 5. Inward leakage results from individual sequential 3-point sample measurements for Suit A

Exercise	Inward leakage (%)												Location exercise mean (%)			**Mean for exercise (%)**
	Subject 1						Subject 2									
	Suit 1			Suit 2			Suit 3			Suit 4						
	Head	Chest	Leg	Head	Chest	Leg	Head	Chest	Leg	Head	Chest	Leg	Head	Chest	Leg	
Standing	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**<0.001**
Walking 5 km/hr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**<0.001**
Moving object table to shelf	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	**<0.001**
Squatting 5/min	<0.001	<0.001	<0.001	0.010	0.001	0.003	0.003	0.001	0.012	0.003	0.002	<0.001	0.004	<0.001	<0.004	**<0.003**
Suit location mean	<0.001	<0.001	<0.001	<0.001	<0.001	<0.004	<0.003	<0.001	<0.002	<0.002	<0.001	<0.001	**Overall suit A mean <0.002** Overall suit A SD >0.002			
Suit location SD	>0	>0	>0	>0.001	>0	>0.006	>0.005	>0	<0.001	<0.001	<0.001	>0				
Suit mean	<0.001			<0.002			<0.001			<0.001						
Suit SD	>0			>0.003			>0.001			>0.001						
For the purposes of calculation, values given as <0.001 are treated as 0.001, but the consequences of the inequalities are considered in the stated results for means and standard deviations.																

Table 6. Inward leakage results from individual sequential 3-point sample measurements for Suit B

Exercise	Inward leakage (%)												Location exercise mean (%)			**Mean for exercise (%)**
	Subject 1						Subject 2									
	Suit 1			Suit 2			Suit 3			Suit 4						
	Head	Chest	Leg	Head	Chest	Leg	Head	Chest	Leg	Head	Chest	Leg	Head	Chest	Leg	
Standing	<0.001	0.002	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.003	<0.002	**<0.002**
Walking 5 km/hr	<0.001	0.007	0.004	<0.001	0.003	0.006	0.008	<0.001	<0.001	<0.001	0.006	0.007	<0.003	<0.004	<0.005	**<0.004**
Moving object table to shelf	<0.001	0.001	0.002	<0.001	0.002	<0.001	0.007	<0.001	<0.001	<0.001	0.002	0.001	<0.003	<0.002	<0.001	**<0.002**
Squatting 5/min	<0.001	0.233	0.003	<0.001	0.019	0.479	0.006	0.005	0.134	0.001	3.480	0.401	<0.002	0.934	0.025	**<0.397**
Suit location mean	<0.001	0.061	<0.003	<0.001	<0.006	<0.123	<0.006	<0.002	<0.034	<0.001	<0.001	<0.001	**Overall suit B mean <0.101** Overall suit B SD >0.507			
Suit location SD	>0	0.115	>0.001	>0	>0.009	>0.238	>0.003	>0.002	>0.067	>0	1.774	>0.199				
Suit mean	<0.021			<0.014			<0.043			<0.326						
Suit SD	>0.067			>0.038			>0.137			>1.000						
For the purposes of calculation, values given as <0.001 are treated as 0.001, but the consequences of the inequalities are considered in the stated results for means and standard deviations.																

5 DISCUSSION OF RESULTS

5.1 PRACTICAL ASSESSMENT

The protective performance of Suit A is higher than that of Suit B. So much so that the great majority of the inward leakage measurements made on Suit A are below the detection limit of our measurement system. This level of protection is admirable, but of little use when investigating the relative merits of the proposed alternative measurement systems. It was for this reason that we deliberately compromised the level of protection offered by Suit B, by not sealing down the closure flaps, in an attempt to induce some measurable level of suit leakage. This appears to have been successful, in that the levels of protection observed in different parts of this suit are very different, with the chest region (adjacent to the unsealed closure zip) showing the highest leakages.

We have found differences, sometimes quite large, between the measured inward leakage values from the different suit locations for both suits. Where there are appreciable levels of suit inward leakage, the simultaneous 4-point measurement does not give a representative average value for the whole suit, and has an inevitable tendency to mask local measurements that are significantly higher than the other points being sampled.

Despite the fact that the simultaneous and sequential sampling approaches used here were carried out on the same suits and subjects, and were made during the exact same test exercises, the resulting inward leakage measurements lead to a difference in classification of Suit B between the two approaches. Suit A gives a clear Class 5 using the simultaneous sample method, but only just manages to achieve the same classification using the sequential approach. However, these classifications assume that the same performance criteria can and should be used to assess simultaneous and sequential samples. Section 5.2 presents the argument that this should not be the case.

Exercises producing the highest measured levels of inward leakage were squatting, followed by walking. This ties in with the observation of the largest in-suit pressure swings during these exercises. Observed levels of inward leakage during standing and moving the object between desk and shelf height were similar and low. One or both of these exercises could be omitted from the test sequence without detrimentally affecting the rigour of the assessment.

5.2 THEORETICAL ASSESSMENT

On the assumption that the level of protection required from an air-fed suit is constant over the whole body of the wearer, the inward leakage performance criteria for several simultaneous samples cannot be the same as for an individual sample. To illustrate this point, consider the following hypothetical but not unrealistic situation:

There are four sampling sites within a suit - leg, chest, arm, mouth.

The relevant pass/fail limit, based on an assessment of a "safe" local dose, is an inward leakage of 0.05%.

The individual inward leakages into the suit present at different sites are:

Leg -	***0.02%***
Chest -	***0.09%***
Arm -	***0.02%***
Mouth -	***0.01%***

Individually, three of these sites pass the assessment against the 0.05% criterion, but one fails, so the suit is not providing the required level of protection to the wearer as a whole.

If the four samples are combined before being analysed, they should give an overall value of 0.035%. This is an overall pass against the 0.05% criterion, yet the chest region is exposed to a significantly higher "unsafe" level of leakage.

If the three body samples are combined, the body average will be 0.043%. This is still an overall pass, yet the chest region is still exposed to an "unsafe" level of leakage.

To ensure that no sampled region of the suit can exceed the concept of the "safe dose", the performance level based on a measurement from more than one sample location needs to be reduced in comparison with that based on a single sampling site as follows:

S = Single site leakage limit

N = Number of sampling locations combined to give an "averaged" leakage measurement

Averaged site leakage limit must not exceed *S/N*

This limit, set to ensure that no one site of those being combined can exceed the single site limit, may result in "false failures" where the sum of the individual site leakages being combined lies between a value of *S/N and S*N*. **This is an inescapable consequence of combining samples before analysis.** If these false failures are not acceptable, then the concept of combining samples before analysis must be abandoned, and sequential single site measurements made instead.

A further consequence of adopting the simultaneous multi-point sample approach, and hence the reduced inward leakage requirement, would be practical difficulty for test houses in reliably measuring such low values. The existing pass level for Class 5 suits requires measurement down to an inward leakage of 0.002%. Two of the laboratories involved in the testing only claim a detection limit of 0.001% for their detection systems. With two or more simultaneous samples being combined for inward leakage assessment, this renders the necessary Class 5 pass/fail level at or below the detection limit for these laboratories, and would prevent reliable assessment of suit performance at these high levels of protection. Rectifying this situation would mean achieving at least an order of magnitude improvement in detection limit, and this presents considerable technical difficulties.

As an illustration of the consequences of applying a numerically lower pass/fail criteria for simultaneous samples, Table 2 would need to be modified to the values shown in Table 7 for our 4-point sampling system.

Table 7. Modification of Table 2 to accommodate the changes necessary to ensure that no one sampling point within the suit falls below the current inward leakage levels allowed in EN 1073-1, for simultaneous 4-point samples.

Class	Maximum value of mean inward leakage during exercise of	
	One activity (%)	All activities (%)
5	0.001	0.0005
4	0.0025	0.00125
3	0.005	0.0025
2	0.01	0.005
1	0.025	0.0125
Note 1. Maximum value is calculated as the average performance over all test sequences.		

Assessment of Class 5 equipment would no longer be possible for two of the three laboratories participating in the Task Group. Suit B still fails to achieve even Class 1 performance, and the performance of Suit A drops from Class 5 to Class 3.

The only valid alternative to this lowering of pass/fail criteria for simultaneous samples is an acceptance that some locations within the suit are not required to provide the same level of protection as others. For example, if higher levels of protection are required to be present in the immediate breathing zone than in the rest of the suit, the same pass/fail criterion could be applied to a single sample from the breathing zone and a multi-point sample from elsewhere in the suit, with the relative reduction in protection being factored by the number of sampling sites being combined. There would need to be a technical assessment and justification of this approach on radiological safety grounds for suits protecting against radioactive particles, and on toxicology grounds if the same scheme is considered for chemical protective suits, and the validity of this approach is likely to depend on the hazardous properties of individual substances that the suits may be used against.

5.3 SUGGESTED PROTOCOL

There is general agreement in the Standards committee that more than one sampling point is necessary within the suit. The main driver for proposing the combination of multiple sampling points within the suit into a single analysed sample is to simplify and speed up the testing of the suits. Based on the findings in this short study, the following protocol is likely to provide the most detailed information on suit performance, with the minimum of additional testing effort over and above that which is currently required for EN 1073-1.

- Sample from three locations within the suit – suggest breathing zone, body and leg.
- DO NOT combine the samples before analysis, but sample each one sequentially during exercises.
- Use a test exercise protocol involving only walking and squatting.

These findings will be fed into the Task Group for further discussion on the development of the revised standard.

6 CONCLUSIONS

1. It is practically possible to make in-suit measurements of inward leakage using a single sample drawn from multiple points within an air-fed suit.

2. Both simultaneous and sequential sampling approaches provide a more realistic and relevant measure of suit protective performance than the existing single-point breathing zone measurement required in EN 1073-1.

3. The results obtained from simultaneous samples do not agree well with the mean value of separate sequential samples drawn from the same suit locations where appreciable levels of inward leakage are present.

4. Combining several samples before analysis has the effect of masking single high values. Individual sequential samples give the greatest resolution and contrast in suit assessment and hence the most rigorous performance measurement.

5. The same pass/fail criterion cannot be applied to both single samples and multi-point simultaneous samples if consistent levels of protection are to be applied throughout the suit. The pass/fail criterion for simultaneous samples must be reduced by a factor of the number of points sampled if consistent levels of protection are to be ensured.

6. Using this reduced pass/fail criterion also has the consequence of the possibility of false failures under some conditions of inward leakage.

7. Levels of inward leakage that require to be measured to assess the highest performing class of suit would be reduced below the detection limits commonly achievable in the participating test laboratories.

8. Acceptance of a single pass/fail criterion throughout the suit where a mixture of single and simultaneous samples is used for assessment also accepts the concept of different levels of protection in the sampled regions. For example, a single sample from the breathing zone, and three other simultaneous samples drawn from the leg, body and arm regions, effectively apply one third of the level of protection to the body compared with the head. Consideration from radiological / toxicological protection stances would be necessary before this approach could be adopted.

9. Walking and squatting exercises were more demanding for the suit than standing and moving an object from table to head height. These latter two exercises could be deleted from the test protocol to reduce the test duration.

10. A protocol of sequential sampling from three suit locations during a test exercise sequence involving only walking and squatting is proposed.

11. The suits tested did not maintain positive pressure during the test exercises.

7 REFERENCES

EN 1073-1:1998 Protective clothing against radioactive contamination – Part 1: Requirements and test methods for ventilated protective clothing against particulate radioactive contamination. CEN, Brussels

EN 1073-2:2002 Protective clothing against radioactive contamination – Part 2: Requirements and test methods for non-ventilated protective clothing against particulate radioactive contamination. CEN, Brussels

EN ISO 13982-1:2002 Protective clothing for use against solid particulates – Part 1: Performance requirements for chemical protective clothing providing protection to the full body against airborne solid particulates (type 5 clothing), CEN, Brussels

EN ISO 13982-2:2004 Protective clothing for use against solid particulates – Part 2: Test method for determination of inward leakage of aerosols of fine particles into suits. CEN, Brussels

8 APPENDIX A

This appendix contains the circulated instructions to round-robin participants. It is the form of amended text taken from the draft-revised version of EN 1073-1.

Annex B (normative)

Total inward leakage test

B.1 Principle

The subject wearing the suit under test, walks on a treadmill over which there is an enclosure. Through this enclosure flows a constant concentration of the test agent (sodium chloride (NaCI)).

The air inside the suit is sampled to determine the test agent content. The sample is extracted through ~~a~~ probes placed inside the suit. ~~Another probe measures~~ The pressure inside the suit is also measured.

The airflow rate to the suit is adjusted and maintained at the manufacturer's minimum design flowrate. For typical arrangement see Figure B.1.

B.2 Test subjects

For the test, persons shall be selected who are familiar with using such or similar equipment and whose medical history is known to be satisfactory. ~~The subjects shall be medically examined and certified fit to undertake the test procedures.~~ The necessity of a medical examination before, or supervision during the tests shall be at the Testing Officers discretion.

Prior to the test there is an examination that the suit is in good working condition and that it can be used without hazard. There shall be two test subjects, each of whom shall test two samples ~~Two chemical protective suits shall be tested, each type being tested on two test subjects;~~ one of these suits shall be conditioned according to 5.2.

If more than one size of suit is manufactured, the test subjects are asked to select the appropriate size.

The test subjects are asked to read the manufacturer's fitting instructions and, if necessary, are shown how to fit the suit correctly by the Test Supervisor, in accordance with the fitting instructions. After fitting the suit each test subject is asked "Does the suit fit?". If the answer is "YES", continue with the test. If the answer is "NO", take the subject off the panel and report the fact.

Information relating to the test persons (weight, height, age, gender) shall be recorded.

B.3 Sodium chloride aerosol

B.3.1 Aerosol generator

The aerosol generator is described in 8.16.3.2.1 of EN 136:1998 -> link to a test std EN 13274-1

B.3.2 Test agent

The mean sodium chloride concentration within the enclosure shall be as described in 8.16.3.2.2 of EN 136:1998.

B.3.3 Detection

The test atmosphere should preferably be analysed for NaCI continuously by means of a suitable flame photometer. The probe for sampling the test atmosphere must be positioned near the hood. The NaCI concentration inside the suit is analysed and recorded by a flame photometer. This concentration, measured within the head section of the suit being a measure of the total inward leakage.

The test is performed at ambient temperature and a relative humidity of less than 60 %.

B.3.4 Flame photometer

A flame photometer shall be used as described in 8.16.3.2.3 of EN 136:1998.

B.3.5 Sample pump

If no pump is incorporated into the photometer an adjustable flow pump is used to withdraw an air sample from the suit under test. This pump is so adjusted as to withdraw a constant flow of 1 l/min to 3 l/min from the sample probe. Dependent on the type of photometer it may be necessary to dilute the sample with clean air.

B.3.6 Sampling of chamber concentration

The chamber concentration is monitored during the test using a separate sampling system to avoid contamination of the suit sampling lines. It is preferable to use a separate flame photometer for this purpose. If a second photometer is not available, sampling of the chamber concentration using a separate sampling system may be made. However, time will then be required to allow the photometer to return to a clean background. Figure A.1 shows a typical sampling arrangement.

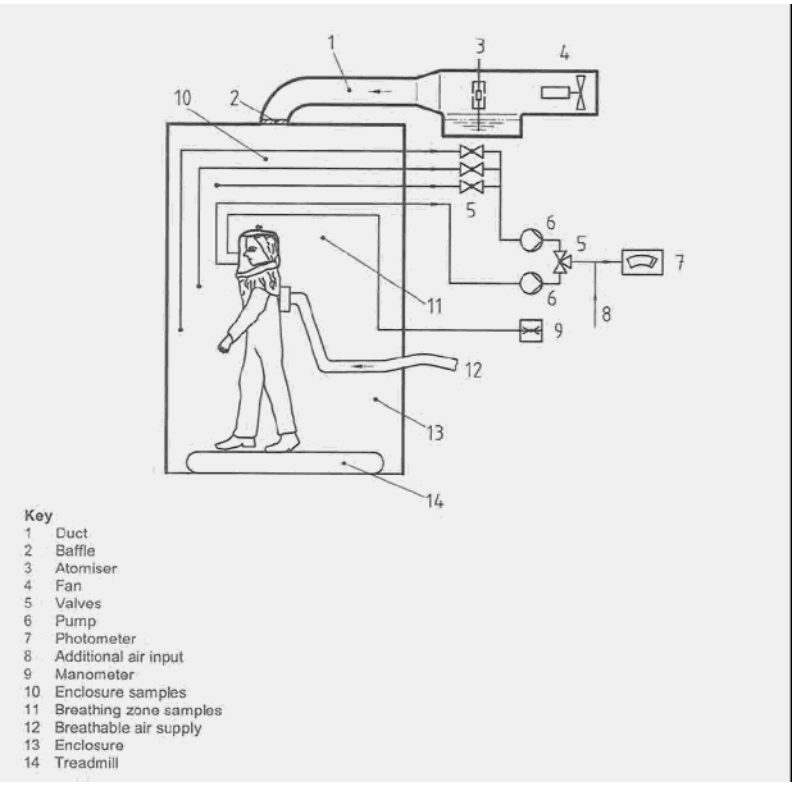


Figure B.1 — Typical arrangement of inward leakage test using sodium chloride aerosol

B.5 Sampling

B.5.1 General

Five sampling probes are used during the test:

- four constructed as described in B.5.2, one which shall be used to measure the challenge concentration and three, the concentration inside the suit (at the knee height - lateral, at the back of the waist, at the arm between the shoulder and the elbow),

- another one constructed as described in B.5.3. This one is used to measure the concentration in the respiratory area.

The air extracted from the ~~four~~ three sampling probes located in the body of the suit (~~in the respiratory area ,~~ at the knee height - lateral, at the back of the waist, at the arm between the shoulder and the elbow) is mixed by means of a device allowing a simultaneous sampling as described in B.5.5.

B.5.2 sampling probes for the body and the challenge concentration

Sampling probes used to measure the concentration at the knee height, at the back of the waist, at the ~~fore~~arm and for the challenge concentration are constructed as shown in figure B.2. Each dimension shall be within ± 10 %.

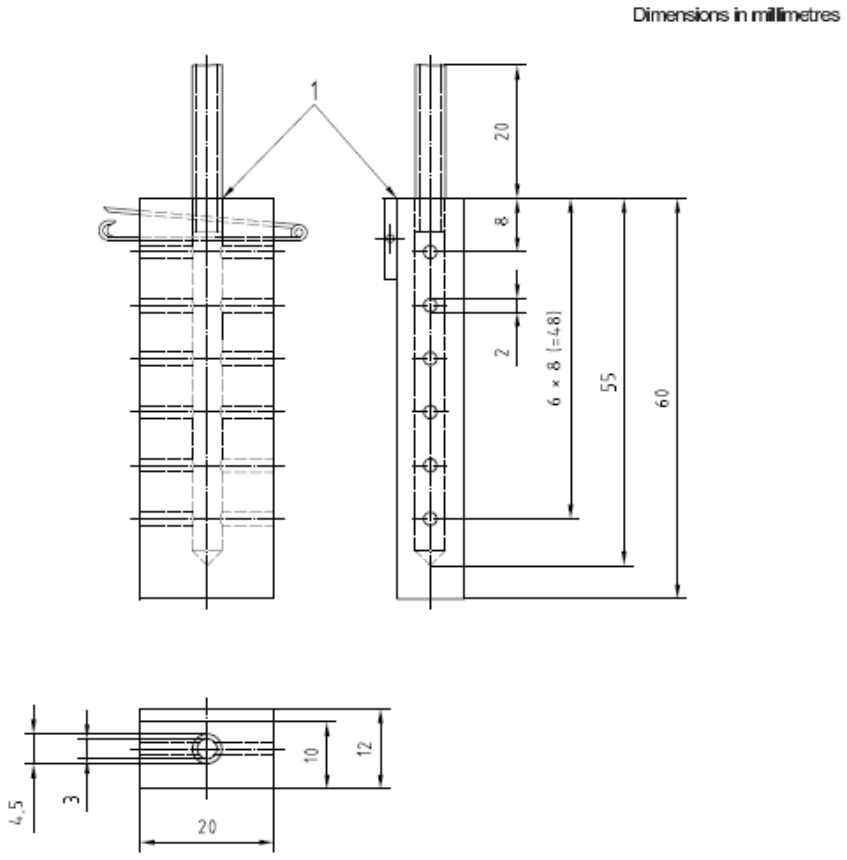


Figure B.2 – One of the 2 types of sampling probe

Each probe is fitted onto a length of suitable transparent plastic tube such that under static conditions the flow rate through each is the same ± 10 %.

B.5.3 sampling probe for the respiratory area

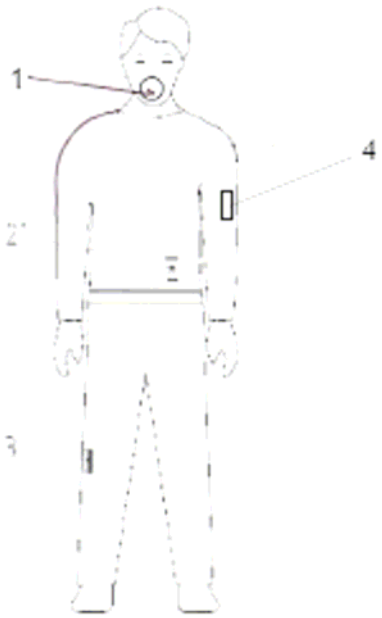
The probe consists of a length of suitable plastic tube fitted with a plastic ball of approximately 20 mm diameter and having eight holes each of approximately 1,5 mm diameter spaced equidistant around the circumference of the ball.

The probe shall be positioned so it touches the lips of the wearer.

NOTE It can be necessary to perforate the faceblank or visor and an inner mask (if fitted) for testing purposes. A thin tube, as short as possible, leading into the inner mask is connected in a leaktight manner to the analysing instrument. The sampling rate should be constant and the range between 0,15 l/min and 0,3 l/min.

B.5.4 position of sampling probes during the test

The three probes for measuring the concentration inside the suit shall be positioned close to the body of the test subject but not covered by any other clothing, at the following positions as shown in figure B.3:



Key

1	in the respiratory area: the probe shall be positioned so it touches the lips of the wearer
2	at the back of the waist
3	at the knee height, lateral
4	at the arm between the shoulder and the elbow
a	Probe 2 is positioned on back

Scheme -> “External lateral” (arm + knee)

Figure B.3 – positions of the four sampling probes on body of test subject

Sampling probes shall not be positioned directly onto the skin, but shall be fixed onto the underwear.

B.5.5 Collecting device used for a simultaneous extraction of the air from the ~~4~~3 sampling probes located in the suit

Three streams shall be combined into one in such a way that the flow rate from each is approximately the same.

~~This collecting device shall be constructed as described in figure B.4 and it shall fixed on the test subject, for example on the torso.~~

~~Figure B.4 – collecting device used for sampling air in the suit~~

~~Each tube is fitted with an internal diameter of 4,0 mm.~~

B.5.6 Sampling lines

The sampling lines shall be made of a stiff enough material so that the lines are not pinched when the test subject moves.

The sampling lines inside the suit shall be fixed close to the body of the test subject and shall pass through the material of the suit by any airtight mean.

~~The sampling lines from the probes inside the body of the suit shall be connected on the collecting device which allows sampling the air from all the sampling probes in the suit simultaneously. The length of the sampling lines leading to the collecting device shall be the same in order to minimize the effects of imbalance between the different sampling probes.~~

Note: the fixings of the sampling lines and the pass-through should have as little influence on the fit of the suit as possible and should not impair the movements of the test subject.

B.6 Test chamber

~~This should be made from transparent material and has a minimum cross-sectional dimension of 0,7 m (see Figure B.1). It should be supported with adequate clearance above the head of the test subject and extend down to the surface of the treadmill. The test agent enters the top of the chamber through a flow distributor and is directed downward over the head of the test subject at a flow rate of at least 0,12 m/s. This flow rate should be measures close to the subjects head. In addition the flow rate should not fall below 0,1 m/s inside the effective working volume (0,1 m from the chamber wall and above a height of 0,75 m).~~ The concentration of the test agent inside the effective working volume has to be checked to be homogeneous. The test chamber shall be large enough to comfortably allow all of the test exercises to be carried out and allow visual observation of the test subjects throughout the tests.

B.7 Treadmill

A level treadmill capable of maintaining a constant speed of $(5 \pm 0{,}5)$ km/h ~~.~~shall be installed in the chamber.

B.8 Pressure detection probe

A~~nother~~ probe ~~I~~ shall be fitted near to the sampling probe for respiratory area and ~~I~~ shall be connected to a pressure sensor.

B.9 Test procedure

~~**B.9.1** The test subject I shall be dressed in the suit according to the instructions for the type of suit under test. The test subjects shall be informed that if they wish to adjust the suit during the test they may do so. If this is done the relevant section of the test will be repeated having allowed time for the system to resettle.~~

The subjects shall have no indication of the results as the test proceeds. The following protocol is followed:

~~B.9.2 Test protocol~~

Inward leakage and pressure shall be monitored at both respiratory and body sampling points during activities d to k. These activities may be repeated if necessary.

Activity	Duration of the activity (min)	Exercise
a. Dress subject in suit, don boots gloves etc. as required according to manufacturers instructions	/	/
~~b. Don boots gloves etc. as required according to manufacturers instructions~~	~~/~~	~~/~~
c. Subject to enter test chamber and connect tubing to sample point (no test agent)	/	/
d. Establish background reading ~~at sample points~~ with subject standing still (no test agent)	3	Standing still
e. Start test agent and allow to stabilise		
f. Record leakage and pressure ~~at sample points~~ with subject standing still	3	Standing still
g. Start treadmill	/	/
h. Record leakage and pressure ~~at sample points~~ with subject walking at about 5 km/h	3	Walking at 5 ± 0,5 km/h
i. Stop treadmill	/	/
j. Record leakage and pressure ~~at sample points~~ with subject moving arms up and down above head and looking upward, e. g. lifting object (half brick) from desktop shelf level	3	Moving arms up and down (5 / min)
k. Record leakage and pressure ~~at sample point~~ with subject doing continuous squats	3	Squatting (5/min)
l. Stop test agent and allow to disperse with subject in chamber	/	Standing still
m. Disconnect sample tubes and remove subject from test chamber. Undress subject	/	/

NOTES

- The total trial time can vary, all times are approximate and are to stable conditions.
- When doing squats or moving arms up and down, a slow deliberate action is required, say one every 3s, which means 5 squats/min or 5 cycles/min when moving arms up and down.

- Analyse results over final 2 min of each exercise period to avoid carry over of result from one exercise to another.
- Record challenge chemical continuously using a separate detector (if possible).
- Record the pressure inside the suit over the whole time.

B.10 Assessment of results

Calculate the percentage total inward leakage (T.I.L) for each exercise as follows:

$$T.I.L = \frac{C_2}{C_1} x100 \ [\%]$$

Where

C_1 = concentration in enclosure

C_2 = mean concentration ~~in breathing zone~~ at the sampling point for each exercise

Calculate the arithmetic mean percentage total inward leakage for ~~the whole exercise program~~ exercises f, h, j, k for all test subjects. These results are reported for classification of performance.

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Assessment of inward leakage tests for air fed suits

This report describes work carried out as part of an inter-laboratory round-robin exercise to investigate the practicality and usefulness of a simultaneous multi-point in-suit sampling protocol for the assessment of inward leakage into air fed suits proposed for the revision of the relevant European Standard. HSL had concerns that this revised protocol would not produce the optimum level of information on suit performance, and would limit the highest levels of protection that could be measured.

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