

Development of an Automated System for Respirator Quantitative Fit Testing

Authors:

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1. Introduction:

One of the most critical requirements of military masks is that they provide respiratory and eye protection to the combat soldier while he is performing his mission in a battlefield concentration of chemical agents. Since testing using chemical agents in a battlefield situation is not possible, the most desirable alternative, laboratory testing using chemical simulants, is the current method of respirator evaluation within both the military and the civilian communities.

The Respirator Test and Evaluation Group, Individual Protection Division of the Physical Protection Directorate at the US Army Chemical Research Development and Engineering Center (CRDEC), installed an automated quantitative fit test system (QNFT) for the respirator evaluation in January 1985. This concluded a development program which was initiated in May 1984. The automated system replaced the previous method of data collection which had been in operation at CRDEC since March 1983. The automated QNFT system features a computer controlled forward light-scattering photometer detection system which necessitated major modifications to the original detection system. First, the detection unit was modified to ensure hardware compatibility with the data acquisition and control units (DACU). Manual valving was replaced by solenoid valving and mechanical switches were replaced by electronic relays (Figure 1). This upgrade gives unprecedented accuracy and reliability of the detection equipment. This level of performance is achieved by the strict control and monitoring of testing by the DACU which is the heart of the automated system. Another unique feature of the automated QNFT system is

that it was designed to be software driven to allow flexibility in the research environment.

The automated QNFT system has increased the group's testing capacity by fifty percent and reduced data analysis time from days to minutes. Originally, strip-chart recorders were used to collect the test data; these data were then analyzed, calculated, and compiled by hand. This method of data collection made the previous system very labor-intensive. The new automated QNFT system allows the operator to focus his/her attention to the ongoing exercise scenario underway in the test chamber, thus insuring that each and every test is conducted exactly the same way each

and every time. This system has also allowed the Individual Test & Evaluation Team to expand its test capabilities by reducing manpower requirements and greatly increasing data analysis efficiency and accuracy. The system is virtually commercially available, the software is flexible enough to adapt to a myriad of fit testing needs, and can be set up and functional with a minimum of effort.

This automated system would be useful to any organization, civilian, or military, which conducts respirator fit testing on a routine basis. Many NATO countries have already seen the instrumentation demonstrated and expressed an interest in acquiring an identical system for their respirator

FLOW SYSTEM

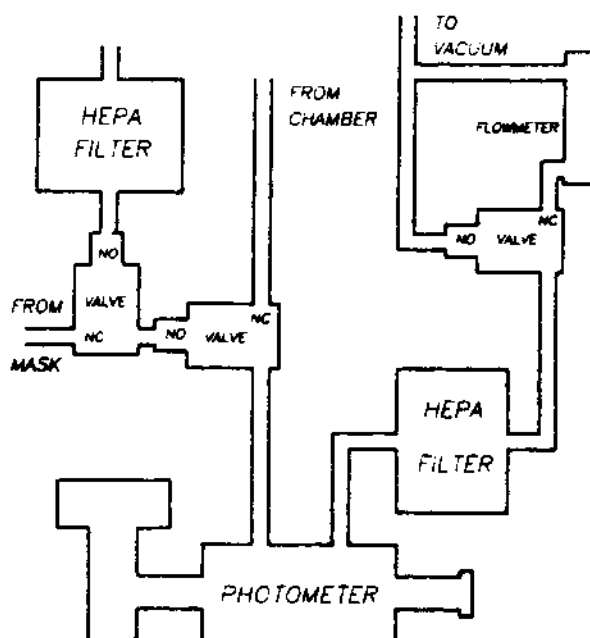


Figure 1

research. The system has also been demonstrated to the National Institutes for Occupational Safety and Health (NIOSH). All of these organizations have expressed considerable interest in CRDEC's technology.

2. Background:

In March 1983 CRDEC acquired the capability to conduct oil aerosol quantitative fit testing by contracting the technical services of the Industrial Hygiene group of Los Alamos National Laboratory (LANL). The test facility required a staff of nine full-time personnel to operate at full capacity. A typical test would be conducted in the following manner:

First, a group of test subjects would receive an orientation class on the importance of such factors as fit, sizing, and wearing of a protective mask. During the orientation period, the subjects would familiarize themselves with the components of the mask, and repeat a series of supervised donnings and doffings. Once the subjects felt confident with the donning procedures, he/she would then don their protective mask, enter the test chamber, and connect their sample probe lines to sampling ports located on the wall of the test chamber.

Once connected, the test operator regulated the flow of aerosol (1 liter per minute) that is drawn from inside the test chamber. Once the flow has been set at the appropriate value, the operator ran through a manual sequence of valve manipulations and detection limits of the photometer. When the calibration of the photometer was complete and lower limit stability achieved, the operator rotated the sample valve to begin sampling from the subject's respirator. The subjects were then instructed to begin the first of a series of ten, one minute exercises. The start of each exercise was indicated by marking the integrated portion of the strip-chart recorder. At the end of each exercise the operator counted and recorded the number of integrator counts.

In the number of integrated counts recorded represents the amount of aerosol particles that have penetrated the seal of the respirator. Upon completion of the test, the subjects are instructed to disconnect their sample lines and exit the

chamber. The data are collected and analyzed at the end of each test day. Analyzing the test data was slow and tedious requiring a series of independent reviews to ensure against errors. A minimum of one week was required to analyze and process one week of test data. The XM40 mask development program created the need for a new test system which could handle the large testing load and rapid turn around time requirements.

3. Automated System

Overview

The new automated system, which was developed to meet unique testing needs, is a computer software based system. The computer eliminates the need for an operator to change valves or to perform analysis functions. The operator has only to input the test parameters and follow the prompts given by the computer. A typical test would be run in the following manner:

When the program is running, the CRT displays on the screen the following "soft" key options:

- PRE-START
- START
- CHAMBER
- FINISHED

The PRE-START key is used during start up and enables assignment of a storage location for the data. When the PRE-START key is depressed the following menu is displayed:

- (C) Create New Data File
- (R) Re-initialize Existing File
- (A) Assign I/O Path
- (E) Exit Pre-start

The first option, "Create New Data File," is used to create a new BDAT type data file capable of storing 40 tests. The operator can choose any eight digit name for the file. The second option, "Re-initialize Existing File," clears old data from a file and prepares the file to accept new data in the first data storage register. All data previously stored in the file are lost if this option is used. The third option, "Assign I/O Path," allows data to be stored in an

existing file without disturbing any data already stored in the file. After executing any of the "soft" key routines, the operator is automatically returned to the beginning of the program. If the operator wishes to exit the Pre-start section without execution of any of the three data storage options, the fourth option, "Exit Pre-start," can be used. The operator selects the desired option by typing in the appropriate letter which precedes each option and then pressing the <CONT> key. Once the operator has executed one of the options and assigned a storage location for the data, testing can begin.

The start "soft" key is used to initialize the test sequence. When the start key is executed the operator is instructed to key in specific test information (left and right subject number, concept, trial, and mask identification number). Upon keying in the test information, the operator has the capability to make any necessary changes to the test information. The computer then prompts the user with the message, "When subjects are ready, press <CONT> to begin test sequence." This permits the operator to make any final adjustments to the information just keyed in prior to initiation of the test.

When the operator determines that the test is ready to proceed, the continue key is pressed which activates a series of solenoid valves which enables monitoring the status of the aerosol concentration by gathering thirty (30) challenge aerosol sample readings taken at one second intervals from the test chamber. Once the sample readings are collected and stored in memory, the valves are switched to sample clean, filtered air to insure that the straylight (electronic "noise" which can be confused as leakage) is below prescribed limits. When these test parameters are verified, an audible beep is generated, and a prompt is displayed reminding the operator to set the sample flow rate. When the flow rate is adjusted and the continue key is pressed, two linear graphs appear on the screen, one for the left subject and one for the right subject. The X-axis represents the time elapsed and the Y-axis represents the photometer

response in volts DC. This allows for a visual evaluation of the subject's leakage patterns. The computer also displays the current exercise being tested, and the following set of "soft" keys which may be utilized by the operator as necessary:

- a) Re-start the exercise
- b) Re-start the test
- c) Pause the test
- d) Abort the test

When the test sequence is complete, the computer integrates the photometer output readings and uses the integrated chamber concentration taken at the beginning of the test to determine a penetration value for each exercise. The test data are displayed on the screen at the end of the test for the operator to review. The data are then stored on a microfloppy disk along with the test information. The operator then notifies the subjects to exit the chamber.

The two remaining "soft" keys on the main screen perform the following function:

CHAMBER - The chamber control key gives the operator instant access to the status of the

aerosol concentrations inside the chamber.

FINISH - Terminates the program.

4. Details of the System:

4.1 Equipment:

The automated QNFT system is based on the HP 9000 series 200 model 16 Technical computer. This computer was chosen for its high-speed and data handling capabilities, which are derived from the Motorola MC68000 micro-processor, with 16/32 bit architecture. The operating system is the ROM-based BASIC 2.0 with RAM-based BASIC 2.1 programming extensions. The base system has a 229 mm (9 inch) monochrome CRT with 400 x 300 graphics, a detached keyboard, 384K bytes of internal RAM, and a built-in HP-IB interface. The data are stored on a 3 1/2 inch flexible disc by the HP model 9121 dual disc drive which is connected to the controller through the HP-IB interface.

The work-horse of the automated

QNFT system is the HP 3497A Data Acquisition and Control Unit (DACU). The DACU, through various optional plug in cards, receives and executes instructions from the system controller through the HP-IB interface to open and close valves and acquire data. The following option cards are used to perform the various tasks of the DACU:

Five Digit DVM - The DVM assembly is a system quality, 5 1/2 digit, 1 microvolt sensitive DC voltmeter that uses an integrating analog to digital (A/D) conversion technique. The maximum speed of the unit is 300 readings per second in the 3 1/2 digit mode. The automated QNFT system utilizes a speed of 4 readings per second in the 5 1/2 digit mode, which allows maximum sensitivity of the DVM. The DVM digitizes the analog photometer output voltage and sends the data to the system controller.

Twenty channel relay multiplexer - this assembly uses reed relays to allow the DVM to read from as many as 20 different voltage sources. Each channel consists of HI, Lo, and guard lines, and can be randomly accessed or incremented programmably.

Eight channel high voltage actuator - this assembly is an 8 channel high voltage actuator that can switch voltages up to 252 Vrms and a current of up to 2 amperes. This assembly is used to control the solenoid valving inside the photometer.

4.2 Photometer Modifications:

To accomplish total computer control of the testing, a number of modifications had to be made to the photometer. All manual valves and switches had to be changed or modified. Three manual two-way gate valves were replaced by two, three-way solenoid valves and a third valve was added to regulate the sample air flow. Figure 2 is a schematic of the new flow system. The lines were arranged with the filtered air furthest upstream to flush any residual aerosol from the sample lines which prevents any false

SEALING CIRCUIT DIAGRAM

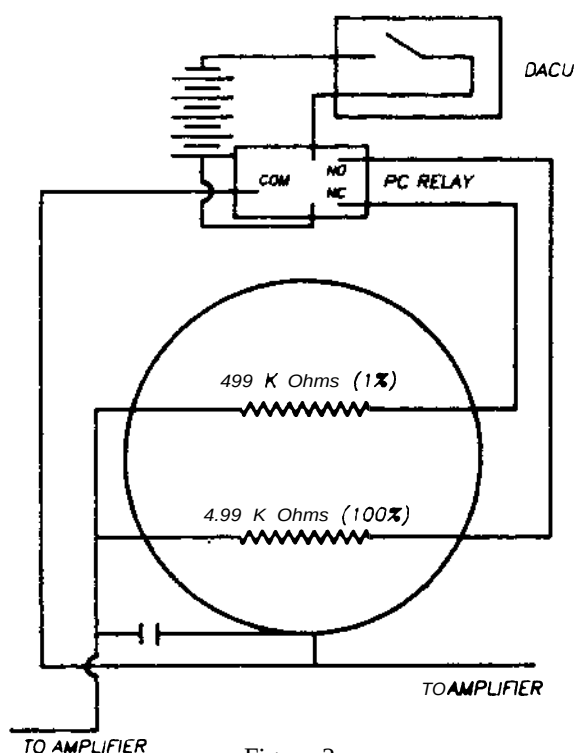


Figure 2

readings due to aerosol trapped in the lines. The third valve allows the air to either flow through a flowmeter set at 1/min or to flow around the meter. The flow around the flowmeter allows for a higher flow rate to aid in clearing the photometer of aerosol.

The manual five position scale selector knob also had to be modified. The scale selector knob allowed the photometer to read over five decades on a one decade strip-chart recorder. With the improved sensitivity and broad range of the DVM only the 100 percent and the 1 percent scales were needed. The 100 percent scale is used when checking the chamber concentration while the 1 percent scale is used in all other cases. This arrangement allows protection factors (pf) between 10 and 20,000 to be measured. Figure 3 is a schematic of the circuit used to automatically switch scales. The switching is done using the 8 channel high voltage actuator which energizes a three position pc relay.

Both the solenoid valves and the scale circuit are wired to the actuator card

through a coupled wire harness which allows for easy connecting/disconnecting of the photometers from the system.

4.3 System Configuration:

The entire system is designed with the system controller as the heart of the system. Figure 1 is a schematic of the system components and the lines of communication which exist between them. The system is run through the system controller by a software based operating system. The software was designed to make the system user friendly and as flexible as possible. The system, through the use of audio and visual prompts, and menus, instructs the operator in all options available for what information is required. The operator is given several opportunities to review the input data and to make corrections as necessary. To prevent the interruption of the test due to inadvertent keystrokes the keyboard is

"locked out."

Since respirator fit testing is still a relatively new science and a standard test procedure has yet to be written the program was set up to allow changes to be made to the test sequence with a minimum of effort. This flexibility was accomplished by dividing the program into subroutines to perform the various test operations. A total of 27 subroutines were used of which 16 are main routines and 6 are support routines, with 3 operation routines linking the entire program together. Table A-1 lists the 16 main routines and the function they perform; table A-2 lists the 6 support routines and their function; and table A-3 lists the three operation routines and their function. The order in which the routines are accessed can be varied by editing only the three operating routines.

Additionally, the test parameters (sample time, number of exercises, length of exercises, frequency of readings, etc.) are all written as variables which are assigned values in the Io subroutine. This allows changes to any of the test parameters by changing only one or two lines of the program. This could also be written to allow changes to be input from the keyboard without editing the program. The organization of the software in this manner allows the flexibility necessary in a research environment.

4.4 Data Storage and Analysis:

The data generated using the automated fit test system is used in key decision making processes in the development cycle of new protective equipment. The data had to be stored in a manner which can allow rapid analysis, manipulation, and recall. The data from a fit test is stored in a BDAT type data file on the flexible discs as a penetration value for each exercise in a separate record along with the subject number, test configuration number, trial number, and mask identification number. The data are then transferred to the test master file which stores the penetration values in the

SYSTEM SCHEMATIC

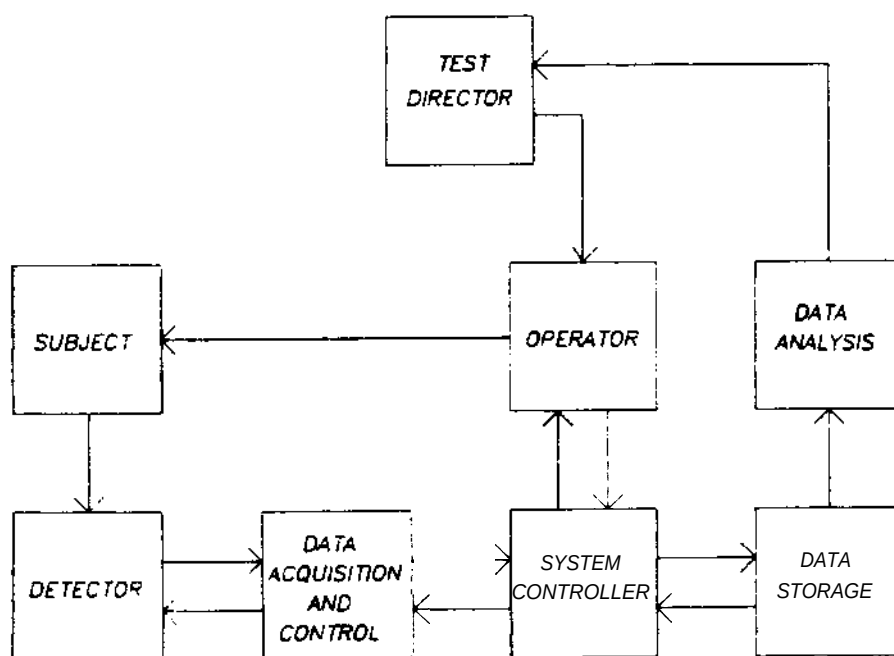


Figure 3

matrix:

X(I,J,K,L)

Where: I = Subject number

J = Concept number

K = Trial number

L = Exercise number

In this form the data through the data analysis program can be quickly compiled and analyzed. Figure 4 is a typical print out of data collected in testing. The data can also be presented graphically for comparative purposes.

5. Summary

The development of the automated fit test system arose out of a need for the

U.S. Army to greatly enhance its respirator test capabilities. The increasing workload and need for higher efficiency made the transition to some type of computer operated system practically a necessity. The primary goal of this effort was the development of a system that required fewer operators to run, faster data reduction and analysis turnaround, as well as greater precision and accuracy.

The automated system described in this paper has met all of the Army's original design goals. An excellent example of how well the system has increased the Army's respirator research was demonstrated recently in the

conduct of the evaluation of the XM40 mask. The Respirator Test and Evaluation Group was able to perform a complete and statistically significant test on a mask, analyze the data and report the results back to the material developer so quickly that it resulted in a decision to accelerate the program by three months. This kind of rapid test program and data analysis would not have been possible without the aid of the automated fit test system. A computer controlled fit test system such as the one described in this paper has the flexibility to be applied to any number of military and civilian applications where large volume testing and rapid data turnaround are required.

PASS/FAIL RATE BY FIX

XM99 MASK DEVELOPMENT
SELF DONNED - W/ HOOD
STANDARD HARNESS
NUMBER OF SUBJECTS 88

***SMALL**	PASS- 0	FAIL- 0
***SMALL**	PASS- 26	FAIL- 1
***MEDIUM**	PASS- 42	FAIL- 8
***LARGE**	PASS- 9	FAIL- 2
***TOTAL**	PASS- 77	FAIL- 11

RANGED PROTECTION FACTOR

XM99 MASK DEVELOPMENT
SELF DONNED - W/ HOOD
STANDARD HARNESS
NUMBER OF SUBJECTS 88

PROTECTION FACTOR	PERCENTAGE	LOWER CONFIDENCE LIMIT @80% RELIABILITY
500	100 X	98.2 *
1667	93 %	89.9 %
3000	93 *	89.9 *
5000	91 \	87.3 %
6667	88 *	83.6 *
10000	85 %	81.2 %
20000	74 *	69.2 %

AVERAGE PENETRATION BY EXERCISE

XM99 MASK DEVELOPMENT
SELF DONNED - W/ HOOD
STANDARD HARNESS
NUMBER OF SUBJECTS 88

Exercise	Penetration Value	Protection Factor	Pass/Fail
Normal Breathing	9.45E-5	10580	81 / ' 7
Deep Breathing	.000154	6493	79 / ' 9
Head Side-to-Side	.000164	6080	80 / ' 8
Head Up & Down	.000157	6350	79 / ' 9
Talking	.0001	9979	78 / ' 10
Sighting the Rifle	.000116	8634	77 / ' 11
Touch Floor & Ceiling	.000193	5179	77 / ' 11
On Knees, Look Up (L&R)	.000181	5510	76 / ' 12
Yawn, Smile, Frown	.000126	7959	77 / ' 11
Sight Binoculars	.000119	8395	81 - ' 7

Figure 4

Table A-1. Main Routines

to -	Assigns the CRT , printer, and DACU addresses and allocates memory for the variables used in the program. Also assigns the exercise length , number , and name .
Screen -	Resets the CRT to prepare for graphic displays.
Graphsetup -	Draws and labels the graphics on which the data from the DACU is plotted.
Plot *	Plots the data from the DACU on the CRT .
Date_acq -	Prompts the DACU to take readings from the photometer and send the data to the controller for storage in the program variables .
Computation -	Integrates the data from the photometers and calculates a protection factor (pf) at the end of each exercise .
Data_storage -	Outputs the pf data for each exercise along with the test information to the flexible storage discs . Also prints the data on the CRT for the operator to review to see if any test anomalies might exist .
Pre_start -	Allows the operator to specify the data storage file on the flexible storage disks.
Data_destinate -	Allows the operator to key in the test information.
Correct_info *	Allows the operator to correct any mistakes made when entering the test information .
Chamber -	Instructs the DACU to switch the valves to sample from the chamber and sends the information from the photometers to the controller where it is integrated and stored in a program variable .
Stray_light -	Checks the photometer output when sampling clean, filtered air to insure that the leadings are below a specified maximum .
Init_variables -	Initializes program variables back to their pretest values after the completion of a test sequence.
Finished -	Terminates the program and assigns the data storage device to it's default value .

Table A-2. Support Routines

Cham_check -	Allows the operator to quickly assess the status of the chamber aerosol concentration.
Init_disk -	Initializes the disc media if an uninitialized disc is used to try to store data .
Abort -	Aborts the test sequence if the operator desires it. The data is not stored and all variables are reinitialized .
Restart_test -	Restarts the test sequence at the first exercise .
Restart_exercise -	Restarts the exercise currently being performed .

Table A-3. Operation Routines

Main_Screen -	Allows the operator to set data storage , initiate the test sequence , or check the chamber concentration .
Initialize -	Accessed the Io and Screen routines .
Measurement -	Controls the test sequence .