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**USAFSAM-TR-89-26**

**AD-A222 626**

**AIRCREW LIFE SUPPORT SYSTEMS  
ENHANCEMENT**

**Robert W. Krutz, Jr., Ph.D.  
Thomas E. Nesthus, Ph.D.  
William R. Scott, Ph.D.  
James T. Webb, Ph.D.  
Cherie J. Noles, M.A.  
Janet F. Wiegman, M.A.  
Rosalind A. Chavez, B.S.  
Bijan Eshaghian, B.S.**

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**KRUG International  
Technology Services Division  
P.O. Box 790644  
San Antonio, TX 78279-0644**

**February 1990**

**Final Report for Period 1 August 1985 - 30 April 1989**

**Approved for public release; distribution is unlimited.**

**Prepared for  
USAF SCHOOL OF AEROSPACE MEDICINE  
Human Systems Division (AFSC)  
Brooks Air Force Base, TX 78235-5301**



**90 05 31 047**

## NOTICES

This final report was submitted by the Technology Services Division, KRUG International, P.O. Box 790644, San Antonio, Texas 78279-0644, under contract F33615-85-C-4503, job order 7930-17-05, with the USAF School of Aerospace Medicine, Human Systems Division, AFSC, Brooks Air Force Base, Texas. Mr. Larry J. Meeker (USAFSAM/VNS) was the Laboratory Project Scientist-in-Charge.

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The voluntary fully informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

  
LARRY J. MEEKER, B.S.  
Project Scientist

  
W. C. ALEXANDER, Ph.D.  
Chief, Crew Technology Division

  
GEORGE E. SCHWENDER, Colonel, USAF, MC, CFS  
Commander

UNCLASSIFIED  
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				FORM APPROVED OMB No. 0704-0183	
1a REPORT SECURITY CLASSIFICATION Unclassified			1b RESTRICTIVE MARKINGS		
2a SECURITY CLASSIFICATION AUTHORITY			3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b DECLASSIFICATION/DOWNGRADING SCHEDULE			4 PERFORMING ORGANIZATION REPORT NUMBER(S)		
4 PERFORMING ORGANIZATION REPORT NUMBER(S)			5 MONITORING ORGANIZATION REPORT NUMBER(S) USAFSAM-TR-89-26		
6a NAME OF PERFORMING ORGANIZATION KRUG International Technology Services Division		6b OFFICE SYMBOL (if applicable)	7a NAME OF MONITORING ORGANIZATION USAF School of Aerospace Medicine (VNS)		
6c ADDRESS (City, State, and ZIP Code) P.O. Box 790644 San Antonio, TX 78279-0644		6b OFFICE SYMBOL (if applicable)	7b ADDRESS (City, State, and ZIP Code) Human Systems Division (AFSC) Brooks AFB, TX 78235-5301		
8a NAME OF FUNDING/SPONSORING ORGANIZATION		8b OFFICE SYMBOL (if applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-85-C-4503		
8c ADDRESS (City, State, and ZIP Code)		10 SOURCE OF FUNDING NUMBERS	PROGRAM ELEMENT NO 62202F	PROJECT NO 7930	PAGE NO 17
					WORK UNIT ACCESSION NO 05
11 TITLE (Include Security Classification) Aircrew Life Support Systems Enhancement					
12 PERSONAL AUTHOR(S) Krutz, Robert W.; Nesthus, Thomas E.; Scott, William R.; Webb, James T. (continued on p. ii)					
13a TYPE OF REPORT Final		13b TIME COVERED FROM: 85/08/01 TO: 89/04/30	14 DATE OF REPORT (Year, Month, Day) 1990, February		15 PAGE COUNT 96
16 SUPPLEMENTARY NOTATION					
17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Decompression sickness; Hypobaric; Ultrasound; Doppler; Hematologic; Review; USAFSAM; Centrifuge; Anti-G suit; High-G training; Anthropometric; (continued on p. ii)		
06	04.10				
23	04				
19 ABSTRACT (Continue on reverse if necessary and identify by block number) USAF Contract #F33615-85-C-4503 with KRUG International, Technology Services Division, supported the Crew Technology Division, USAF School of Aerospace Medicine, in the areas of: human subject acquisition, decompression hazards research, decompression sickness and acceleration database development and refinement, anti-G suit fabrication and testing, chemical defense research, centrifuge support, centrifuge testing of life support equipment, cockpit integration research, oxygen systems research, and human factors research. This final report is a summary of the contract objectives and accomplishments; it includes a complete bibliography of reports generated for the Crew Technology Division. The scientific, engineering, and technical team from KRUG International provided support in accordance with task assignments developed from the statement of work as summarized in each of the 11 areas discussed in this report. Each summary is followed by a review of the accomplishments with reference, where appropriate, to the appendix which lists publications documenting the work completed, in that (continued on p. ii)					
20 DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21 ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a NAME OF RESPONSIBLE INDIVIDUAL Larry J. Meeker, B.S.			22b TELEPHONE (Include Area Code) (512) 536-3811	22c OFFICE SYMBOL USAFSAM/VNS	

12. PERSONAL AUTHOR(S) (continued)

Noles, Cherie J.; Wiegman, Janet F.; Chavez, Rosalind A.; Eshaghian, Bijan

18. SUBJECT TERMS (continued)

Database, Acceleration, Chemical Defense, Shelter processing, Cockpit integration, Oxygen systems, MSOGS, OBOGS, Human factors

19. ABSTRACT (continued)

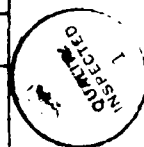
area. Reports which were not published in the open literature or in USAF Technical Reports or Technical Papers have been presented to the Crew Technology Division Contract Monitor for inclusion in the contract file.

## PREFACE

Results of the research sponsored by USAF Contract F33615-85-C-4503 have been published as USAF Technical Reports, USAF Technical Papers, Journal Articles, Symposium Proceedings, and abstracts. Dr. James T. Webb coordinated the efforts of the numerous contributors to produce a usable final report format. Each section summarizes the applicable contract objectives and lists the widely published results and locations of the extensive raw data emanating from the subject contract.

The following authors contributed substantially to the contractual effort by their published works listed in the Appendixes: Ms. Carole L. Baas, Ms. Judith A. Barber, Mr. Bijan Eshaghian, Ms. Estrella M. Forster, Dr. Robert W. Krutz, Dr. Thomas E. Nesthus, Ms. Cherie J. Noles, Dr. Robert M. Olson, Dr. William R. Scott, Mr. Robert E. Simpson, Dr. James T. Webb, and Ms. Janet F. Wiegman. Ms. Emily Gause wrote technical reports on the Chemical Defense Shelter Studies. Essential technical support for centrifuge operations was provided by Mr. Donald J. Smallwood and Mr. Arnold G. Krueger. Fabrication of numerous anti-G suit modifications for research and testing was accomplished by Ms. Cecilia Buendia. Messrs. Edward G. Lee and Frank O. Jacobs were instrumental in training subjects and chamber personnel in Doppler ultrasound technology. Research chamber data on several critical decompression sickness studies were recorded by Messrs. Lee and Jacobs. Ms. Dorothy Baskin provided clerical assistance and data entry support. Ms. Virginia Johnson provided secretarial assistance and data entry support throughout the contract and invaluable assistance in editing the report.

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Unannounced	<input type="checkbox"/>
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Distribution/	
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A-1	



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# AIRCREW LIFE SUPPORT SYSTEMS ENHANCEMENT

## INTRODUCTION

Robert W. Krutz, Jr. and James T. Webb

USAF Contract #F33615-85-C-4503 with KRUG International, Technology Services Division, supported the Crew Technology Division, USAF School of Aerospace Medicine (USAFSAM), in the following areas: human subject acquisition, decompression hazards research, decompression sickness and acceleration database development and/or refinement, anti-G suit fabrication and testing, chemical defense research, centrifuge support, centrifuge testing of life support equipment, cockpit integration research, oxygen systems research, and human factors research. This final report is a summary of the contract objectives and accomplishments; it includes a complete bibliography of reports generated for the Crew Technology Division.

The scientific, engineering, and technical team from KRUG International has provided support in accordance with the task assignments developed from the Statement of Work (SOW) as summarized in each of the 11 areas discussed in this report. Each summary is followed by a review of the accomplishments with reference, where appropriate, to the appendix which lists publications documenting the work completed in that area. Reports which were not published in the open literature or in USAF Technical Reports or Technical Papers have been presented to the Crew Technology Division Contract Monitor for inclusion in the contract file.

PART I:

HUMAN SUBJECT ACQUISITION

Rosalind A. Chavez

A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

In supporting research efforts conducted by the Crew Technology Division, human subjects were required for use in research protocols approved by the USAFSAM Advisory Committee for Human Experimentation (ACHE) in accordance with the contract and Air Force Regulation (AFR) 169-3.

B. ACCOMPLISHMENTS

The acquisition and training of subjects and the completion of all medical requirements were performed as specified by the protocols. Prior to exposure, informed written consent was obtained in compliance with AFR 169-3 as well as with division and branch standard operating instructions. All subjects were compensated for services performed at the contract specified rates. Adequate insurance coverage was maintained as stipulated in the contract in the event any injuries were incurred by human subjects during research studies.

C. COST OF PHYSICAL EXAMINATIONS

At the beginning of the contract, the cost of a Flying Class II physical examination was estimated at \$350. During the course of the contract, a modification was negotiated at which time a more competitive price was submitted (males \$200, females \$215, and \$20 for serum pregnancy tests). Subjects participating in physiological training require an approved AF Form 1042 (Recommendation for Flying or Special Operational Duty). The cost of obtaining the forms from the USAF Clinic/SGP, Brooks AFB, was approximately \$60; however, for the same \$60, the Brooks AFB Clinic would not only perform the physical examinations, but also provide the AF Form 1042s. Therefore, arrangements were made for the Brooks AFB Clinic to perform the physical examinations.

D. CHANGES IN CONTRACT REQUIREMENTS

The contract requirements were changed to provide a broader range of subjects for different studies. Originally, the Flying Class II physical examination was changed to Flying Class III. At the suggestion of the Brooks Clinic/SGP, a new set of physical examination standards was adopted by the ACHE on 4 Nov 87. This change enabled the Flight Surgeon's Office (FSO) to perform the physical examination, Test Subject Physical, required for a particular research study without having to apply the more stringent standards of a Flying Class II or Flying Class III physical examination which was unnecessary in most cases.

E. APPOINTMENT TO QUALITY ASSURANCE PROGRAM

Over the course of the contract, the human subject manager has worked closely with the Crew Technology Quality Assurance/Risk Management (VN QA/RM) coordinator to identify and resolve problems with human subjects used in research protocols within the Crew Technology Division. To improve coordination, the Crew Technology Division Chief appointed the human subjects manager as recorder for the VN QA/RM committee.

## PART II:

### DECOMPRESSION HAZARDS RESEARCH

James T. Webb

#### A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Statement of Work (SOW) in contract F33615-85-C-4503 required KRUG International, Technology Services Division, to:

- Accomplish hypobaric experiments for decompression sickness (DCS) research in accordance with approved human subject protocols.
- Design experiments to determine optimal pressure environments which would eliminate the hazards of decompression sickness (DCS) during high altitude, transatmospheric, and space flight/extravehicular activity (EVA) missions.
- Provide a technical and scientific team to collect data and investigate the relationship of intravenous gas bubbles to DCS.
- Attempt to identify factors relating susceptibility to bubble formation/DCS.

#### B. ACCOMPLISHMENTS

##### B.1 Review of Decompression Hazards Research

USAFSAM-TP-88-10, referenced in Appendix II-A under Webb, et al. 1988, contains a chronological tabulation of protocol parameters, an appendix summarizing results in tabular form, and an appendix listing published works emanating from the contract through October 1988. One of the abstracts cited in USAFSAM-TP-88-10, Adams et al. (1984), was written and published before this contract was approved, but was a report based on preliminary data from a research protocol which continued after the current contract was initiated. Listed in Appendix II-A are all published works which were written before 31 January 1989, relating to decompression hazards research accomplished in accordance with the objectives of this contract. These reports have been submitted to the Crew Technology Division for publication to document the results of the assigned tasks. The raw data from these research projects are located on the VAX SAM780 and are accessible with the HYPOB retrieval system. See Part III of this report for further discussion of research databases.

##### B.2 Cost Analysis Program on Lotus 1-2-3

When protocols for decompression hazards research are developed, a large number of variables determine the cost of the protocol. The interrelations of these variables are too complex for traditional manual accounting methods which are time consuming and inaccurate. Hence, a menu-driven computer program on Lotus 1-2-3 (release 2.01) was developed in which the user can respond to questions about the protocol (e.g., number of subjects, number of exposures, etc.) and produce a hardcopy of the estimated cost. The worksheet is located in the file named "LOTUS\COSTANAL.WK1" on the hard disk in the High Altitude Protection Function (Crew Technology Division, USAFSAM) in Bldg. 170, Room 29. The menu is activated, after retrieving the worksheet named "COSTANAL.WK1", by depressing the Alt-M key and following the

prompts through the two-page menu. A sample cost analysis printout is included as Appendix II-B. This sample is not for actual use, since it contains specific cost estimates based on hypothetical protocol parameters.

### B.3 Doppler Bubble Grading

Subjects are currently monitored for intravenous gas bubbles which are graded by the method of Spencer (1976) as depicted in Table II-1. Grades 1 and 2 bubbling are classified as "not severe" and Grades 3 and 4 are classified as "severe." There are at least three drawbacks with the Spencer method: 1) it is based on heart cycles instead of real time; 2) the grades are not representative of a real number of bubbles; and 3) the difference in numbers of bubbles per minute between some of the grades is several orders of magnitude less than one order of magnitude between other grades.

Work is continuing within the Crew Technology Division to develop a method to electronically discriminate and quantify ultrasonic Doppler bubble signals. Development of a filtering and peak detection device with associated displays would make other methods of bubble grading possible. One such method would grade the bubble signals by five exponential levels (plus zero) which would be roughly equivalent to some of the grades in the Spencer scale as shown in Table II-1. With the exponential method, subdivision of the grades to the desired accuracy is possible; e.g., a grade of 3.25 would convert to 1778 bubbles/h or 30 bubbles/min.



TABLE II-1: SCALES OF DOPPLER BUBBLE GRADING.

<u>Spencer Method<sup>1</sup></u>			<u>Exponential Method<sup>2</sup></u>	
Grade	Description	Bubbles/min (Approximate)	Grade (10 <sup>n</sup> )	Bubbles/h <u>Bubbles/min</u>
Zero	No bubble signals	0	0	$\frac{0 - 9}{0 - .01}$
I	An occasional bubble signal. <sup>3</sup> The great majority of cardiac cycles are free of bubble signals.	0 - 15	1	$\frac{10 - 99}{.02 - 1}$
II	Many, but less than half the cardiac cycles, contain bubble signals	15 - 29	2	$\frac{100 - 999}{2 - 16}$
III	Bubbles in most of the cardiac cycles but not obscuring the heart sounds	30 - ?	3	$\frac{1,000 - 9,999}{17 - 166}$
IV	Numerous bubbles that obscure the heart sounds	?	4	$\frac{10,000 - 99,999}{167 - 1,666}$
			5	$\frac{100,000 - 999,999}{1,667 - 16,666}$

<sup>1</sup>Spencer MP. Decompression limits for compressed air determined by ultrasonically detected blood bubbles. J Appl Physiol 40:229-35 (1976). The bubbles/min approximation is based on a heart rate of 60 beats/min and represents the estimated range of bubble numbers using the Spencer method.

<sup>2</sup>The bubble grade is the exponent of 10 which yields the number of bubbles/h. This value, when calculated per min, is roughly equivalent to the Spencer method.

<sup>3</sup>"great majority" is defined here as 75% of the cardiac cycles.

APPENDIX II-A:

PUBLICATIONS/ABSTRACTS DOCUMENTING DECOMPRESSION HAZARDS RESEARCH

- Baas CL, Olson RM, Dixon GA. Audio and visual ultrasonic monitoring of altitude decompression. Proceedings of the 26th Annual SAFE Symposium, pp. 22-26, Las Vegas, NV, 1989.
- Baas CL, Dixon GA, Hill RC. Effect of a carbon dioxide prebreathe gas mixture on the incidence of altitude-induced decompression sickness. (Abstract) Aviat Space Environ Med 60:506(177) (1989).
- Dixon GA, Adams JD, Harvey WT. Decompression sickness and intravenous bubble formation using a 7.8 psia simulated pressure-suit environment. Aviat Space Environ Med 57:223-228 (1986).
- Dixon GA, Krutz RW. Evaluation of 9.5 psia as a suit pressure for prolonged extravehicular activity. Proceedings of the 23rd Annual SAFE Symposium, pp. 122-125, Las Vegas, NV, 1986.
- Dixon GA, Krutz RW. Female susceptibility to decompression sickness and bubble formation using a simulated 7.8 psia suit environment. (Abstract) Aviat Space Environ Med 57:511(133) (1986).
- Dixon GA, Krutz RW Jr, Fischer JR Jr. Decompression sickness and bubble formation in females exposed to a simulated 7.8 psia suit environment. Aviat Space Environ Med 59:1146-1149 (1988).
- Inderbitzen RS, DeCarlis JJ Jr. Energy expenditure during simulated EVA workloads. SAE Technical Paper #860921. ICES, San Diego, CA, 1986.
- Krutz RW Jr, Dixon GA. The effects of exercise on bubble formation and bends susceptibility at 9,100 m (30,000 ft; 4.3 psia). Aviat Space Environ Med 58:A97-A99 (1987).
- Krutz RW Jr, Dixon GA, Harvey WT. Minimum pressure for a zero-prebreathe pressure suit. SAE Technical Paper #851315. ICES, San Francisco, CA, 1985.
- Krutz RW Jr, Dixon GA, Olson RM, Moore AA. The relationship of intravascular bubbles to bends at altitude. Proceedings of the 23rd Annual SAFE Symposium, pp. 315-317, Las Vegas, NV, 1986.
- Krutz RW Jr, Webb JT, Dixon GA. Determining a bends-preventing pressure for a space suit. Proceedings of the 26th Annual SAFE Symposium, pp. 36-39, Las Vegas, NV, 1989.
- Olson RM, Krutz RW Jr, Dixon GA, Smead KW. An evaluation of precordial ultrasonic monitoring to avoid bends at altitude. Aviat Space Environ Med 59:635-639 (1988).

- Olson RM, Krutz RW, Dixon GA. Validity of ultrasonic monitoring at altitude for bends detection. (Abstract) Aviat Space Environ Med 57:511(131) (1986).
- Smead KW, Krutz RW Jr, Dixon G, Webb JT. Decompression sickness and venous gas emboli formation at 8.3 psia. Proceedings of the 24th Annual SAFE Symposium, pp. 196-199, San Antonio, TX, 1987.
- Webb JT, Dixon GA, Wiegman JF. Potential for reduction of decompression sickness by prebreathing with 100% oxygen while exercising. SAE Technical Paper #891490. ICES, San Diego, CA, 1989.
- Webb JT, Krutz RW Jr, Dixon GA. An annotated bibliography of hypobaric decompression sickness research conducted at the Crew Technology Division, USAF School of Aerospace Medicine, Brooks AFB, TX from 1983 to 1988, USAFSAM-TP-88-10, Oct 1988.
- Webb JT, Olson RM, Baas CL, Hill RC. Bubble detection with an echo-image/Doppler combined probe versus separate probes: A comparison of results. (Abstract) Undersea Biomed Res 16(Suppl):89-90(156) (1989).
- Webb JT, Olson RM, Dixon GA, Krutz RW, Barnicott PT. Oxygen toxicity during 5 simulated 8-h EVA exposures to 100% oxygen at 9.5 psia. SAE Technical Paper #881071. ICES, San Francisco, CA, 1988.
- Webb JT, Olson RM, Krutz RW Jr, Dixon GA, Barnicott PT. Human tolerance to 100% oxygen at 9.5 psia during five daily simulated eight-hour EVA exposures. (Presentation) 26th Annual SAFE Symposium, Las Vegas, NV, 1988. Aviat Space Environ Med 60:415-421 (1989).
- Webb JT, Smead KW, Jauchem JR, Barnicott PT. Susceptibility to decompression-induced venous gas emboli: Hematology and biochemistry. Space Life Sciences Symposium Abstracts (pp. 129-130), Washington, DC, 1987.
- Webb JT, Smead KW, Jauchem JR, Barnicott PT. Blood factors and venous gas emboli: Surface to 429 mmHg (8.3 psi). Undersea Biomed Res 15:107-121 (1988).

APPENDIX II-B:

SAMPLE COST ANALYSIS PRINTOUT

COST ANALYSIS: PREBREATHE WITH EXERCISE		26	MALES
CONTRACT SUBJECT COST		0	FEMALES
	PER SUBJECT	26	SUBJECTS
MEDICAL EXAM, MALE	\$30.00		\$780.00
MEDICAL EXAM, FEMALE	\$30.00		\$0.00
PREGNANCY TESTS (\$20 EACH)	\$20.00		\$0.00
EXAM HRS (4@\$3.35/SUBJECT)	\$13.40		\$348.40
ATTRITION, POST-EXAM	\$14.47		\$376.13
PROTOCOL TNG (\$3.35/HR)	\$26.80		\$696.80
CHAMBER TNG CRS (8HR@\$10)	\$80.00		\$2,080.00
ATTRITION, POST-TRAINING	\$70.57		\$1,834.86
EXPOSURE TIME @ \$10/HR	\$360.00		\$9,360.00
TRAVEL EXPENSES (\$0.20/MI)	\$80.00		\$2,080.00
ATTRITION, DURING PROTOCOL	\$289.39		\$7,524.08
TOTAL	\$964.63		\$25,080.27

CONTRACTOR/USAF COST	BY PARAMETER	BY PROTOCOL
PROTOCOL CONSENT BRIEFING	\$25.00	\$325.00
USAF CHAMBER TEAM/TRAINING	\$508.96	\$1,017.92
PROTOCOL TNG, INSTR COST/ SUBJECT (CNTR @ 10.50/HR)	\$273.00	\$7,098.00
USAF CHAMBER TEAM/PROTOCOL	\$508.96	\$18,322.56
CHAMBER MAINT & DEPREC/DAY	?	\$0.00
MEDICAL MONITOR/HR (CNTR)	\$24.00	\$864.00
(CNTR;3) RES SCI/TECH/HR	\$70.00	\$4,620.00
USAF PRINCIPAL INVEST/HR	\$50.00	\$3,800.00
USAF/CNTR ASSOC INVEST/HR	\$40.00	\$1,640.00
ADMIN/COMPUTER ENTRY/SUBJ	\$30.00	\$780.00
ATTRITION	\$445.58	\$11,585.01
TOTAL		\$50,052.49
SUPPLIES (AV OXYGEN)		\$4,000.00
TRAVEL		\$400.00
		\$4,400.00
GRAND TOTAL		\$79,532.76

## PART III:

### DCS RESEARCH/LITERATURE DATA BASES

Bijan Eshaghian and James T. Webb

#### A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Statement of Work (SOW) required expansion, modification, and maintenance of DCS Research/Literature Data Base repositories for the storage and retrieval of hypobaric experimental data and literature data. The experimental data include extensive anthropometric, flight, and hematologic records.

#### B. ACCOMPLISHMENTS

##### B.1 DCS Research Data Base

B.1.1 Background. The new DCS database was implemented in December 1985; it was designed to accommodate information obtained from USAFSAM human subjects during approved hypobaric experimental protocols. The database contains anthropometric, flight, and hematologic data collected from over 343 different subjects who have participated in approximately 1,655 simulated altitude exposures.

B.1.2 Procedures. The USAFSAM DCS repository is maintained on a VAX SAM780 computer using the VAX Database Management System (DBMS). Information on the DCS program and its structure may be found in the abstract referenced in Appendix III-A (Eshaghian, et al. 1987). The root file "HYPOB.R00" and supporting programs (which run the DCS database) were designed and currently reside in a subdirectory called "HYPOB.DCS\_DBMS" on the SAM780.

A procedure called "MAINDML.BAS" was designed for data entry. A program called "TESTDML.BAS" was written to validate the data after input.

A retrieval program called "HYPOB" was designed to access the DCS repository for statistical information as well as graphs, charts, tables, and other computer outputs. To start the retrieval program, type "HYPOB" at the "\$" prompt and depress the return key which opens a series of command files that declare temporary variables, ready the records, and execute the control program. When the menu appears on the screen, the program is ready to accept commands. Only designated users are given access privileges to the DCS repository.

Detailed documentation on how to retrieve data from the database is available in the files with a file extension of ".RNO".

The publications listed in Appendix II-A are based on information retrieved via the "HYPOB" retrieval programs.

##### B.2 DCS Literature Database Description

B.2.1 Background. The need for a database on scientific literature which discusses decompression sickness (DCS) was partially

addressed in the 1985-1987 period with the development of a DCS Literature Database on the SAM780 VAX. This program was inefficient and inflexible compared to a similar system developed for use on Zenith 248s using the Enable software. The new system is now in full use. To date, 382 articles have been entered, indexed, and verified for accuracy. The Zenith 248s with the DCS Literature Database installed are managed by the High Altitude Protection Function (Crew Technology Division, USAFSAM).

B.2.2 Procedures. The database is called REFS and the actual data file is named "REFS.DBF." All of the data files are in the same directory (ENABLE) as the Enable command files. The sequence of keyboard entries to access the database, after the Zenith 248 system in USAFSAM/VNBD has been turned on, are as follows:

At the C:\> prompt, type "en" [CR] (CR = carriage return or Enter key), depress the "End" key, "U", "D", and "I" keys in sequence, and follow the prompts (see Enable documentation). Before adding articles to the database, please observe the standardization used in previous entries. Standardizing entry procedures simplifies retrieval and post-retrieval editing.

Changing a record (e.g., editing the record which describes the article by Dixon et al., 1986; Appendix II-A) involves these steps: Depress "E" for edit, type in REFS [CR], and use the REFS form. Depress [CR] to skip the index which has not been used to date. To edit only the article mentioned above, use "Where:" to define the search limits; e.g., Where:AUTHORS="Dixon\$"[CR] to retrieve only those articles written by Dixon as the first or only author (the \$ allows anything after Dixon to be included; to search for articles where Dixon is not the first author, add a \$ immediately before Dixon). See the Enable documentation for complete information about how to edit a record and change to another record.

A common use of the database is to generate an alphabetical printed list of articles, usually in the Aviation, Space, and Environmental Medicine (ASEM) journal format (see the sub-heading on Reports from REFS.SS Database). Follow the prompts to have the output sent to the printer. It is possible to limit the search to a code placed in the COMMENTS field or to certain keywords within the KEYWORDS and/or TITLE fields.

B.2.3 Reports from "REFS.SS" Database. All reports will be alphabetized by author/year/source if "Database:REFS.SS" is selected. Selecting a report format from the following list, \*.RPT, and entering that format name (e.g. REFSJ.RPT) after "Using form:" will produce the desired report.

-III-

REFSJ.RPT (JOURNAL FORMAT; ASEM)

AUTHORS. TITLE. SOURCE{.} YEAR; VOLUME{:}PAGES

REFSA.RPT (ALL DATA ON DATABASE)

AUTHORS. YEAR. TITLE. SOURCE{.} VOLUME{:}PAGES. FULL DATE LAB KEYWORDS  
COMMENTS

REFSQ.RPT (QUICK REFERENCE LIST; SET PITCH TO ELITE; 12 CPI)

AUTHORS(30) YEAR(4) SOURCE(38) VOLUME(4){:} PAGES(9)

REFSK.RPT (KEYWORDS IN ADDITION TO JOURNAL FORMAT)

AUTHORS. TITLE. SOURCE{.} YEAR; VOLUME{:}PAGES KEYWORDS

NOTE: {} punctuation inserted during data entry

-III-

APPENDIX III-A:

PUBLICATIONS DOCUMENTING DCS/LITERATURE DATA BASES

Eshaghian B, Besich W, Decelles T. A computerized repository system for collecting and retrieving decompression sickness (DCS) data. (Abstract) Aviat Space Environ Med 58:490(93) (1987).



## PART IV:

### ANTI-G SUIT FABRICATION AND TESTING

Robert W. Krutz, Jr., William R. Scott,  
Janet F. Wiegman, and James T. Webb

#### A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

Several avenues of research were pursued to support the development of a uniform pressure anti-G suit to enhance G-tolerance. A facility was equipped for the timely fabrication of experimental anti-G suits. Structural considerations in designing an improved anti-G suit include the interaction of the anti-G straining maneuver and its refinement with appropriate physical conditioning. Standardization of anthropometric measurement methodology was essential to provide repeatable results. Finally, individual physiologic data from Tactical Air Forces (TAF) fighter pilots had not been integrated with G-tolerance to determine if experimental subjects represented the fighter pilot population. These diverse areas all contributed to the development of better anti-G suits.

#### B. ACCOMPLISHMENTS

##### B.1 Fabrication and Testing of an Advanced Technology Anti-G Suit

Designs of uniform pressure anti-G suits were compared to determine the most promising design to pursue, given that a uniform pressure suit was proven superior in past studies. The results of this comparison showed conclusively that a pneumatic uniform pressure suit was superior to both the reticulated foam anti-G suit, an earlier modified CSU-4/P partial pressure suit, and to the standard CSU-13B/P anti-G suit (Krutz et al., 1988b). The physiologic reasons for the enhanced protection against +G<sub>z</sub> acceleration afforded by the pneumatic full-coverage suit were studied and the results discussed at the 1988 Aerospace Medical Association Scientific Meeting (Krutz et al., 1988a). The full-coverage suit was then flight-tested by pilots at the USAF Test Pilot School (USAFTPS) at Edwards AFB, CA, in both the RF-4C and F-16B aircraft (Helms et al., 1988). The conclusion reached by the pilots indicated that the full-coverage anti-G suit (renamed ATAGS for "advanced technology anti-G suit") was superior to the current operational anti-G suit, particularly in the F-16 mission scenario, and should be pushed into advanced engineering development. Publications/abstracts relating to this task are listed in Appendix IV-A. The raw data from these research projects are located on the Sperry/Univac computer and are accessible with the S2k retrieval system. The seven files which contain the data are controlled by the Systems Engineering Branch. For further information see Section V.B.2.

##### B.2 Life Support Equipment Development Laboratory (LSEDL)

The LSEDL was brought on-line primarily to support the anti-G suit fabrication task; however, it has served many other areas of the contract as well, such as the fabrication of chemical defense ensembles (CDE). The ATAGS was extensively modified in the LSEDL--most of the effort centered on the redesign of the abdominal bladder and structural reinforcement of RF-welded seams. The LSEDL also played a prominent role in the Combat Edge program by

providing an on-site facility for modifying the jerkin used for assisted pressure breathing and the mask-retention bladder used to keep the mask in proper position during pressure breathing. A sizing program for a G-protection system composed of upper and lower garments was proposed (Appendix IV-A; Scott and Simpson, 1989).

### B.3 Physiologic Methods of Enhancing G-Protection

B.3.1 Introduction to the Wingate Anaerobic Test. To augment the G-protection afforded by ATAGS, Wingate Anaerobic Tests (WATs) were conducted to determine the effect of anaerobic fitness on performing the anti-G straining maneuver. The WAT is a brief, maximal-effort, cycle ergometer task which quantifies the ability to perform high-intensity, short-duration work. To date, 100 WATs have been conducted on Tactical Air Command (TAC) pilots and USAFSAM centrifuge test subjects. The data acquisition system, particularly a heart rate monitoring device developed as a result of the WAT research, was presented at the 1988 SAFE Symposium (Appendix IV-A; Wiegman et al., 1989a). The WAT data are available on the SAM780 VAX, account Wiegman, subdirectories TAC.DIR and SUBJ.DIR for the TAC pilot and for the centrifuge test subject data, respectively.

B.3.2 The Wingate Anaerobic Test as an Indicator of Simulated Aerial Combat Maneuvers. The test procedures for the WAT are detailed in USAFSAM ACHE 88-14, which investigates the relationship between +G<sub>z</sub> duration and WAT values for USAFSAM centrifuge subjects. The Wingate test was also used as a physiologic parameter in ACHE #88-21 (Combat Edge, Candidate F-16 Ensemble Evaluation), to assess intersubject differences in anaerobic abilities. Complete results were presented at the 1989 Aerospace Medical Association Scientific Meeting (Appendix IV-A; Wiegman et al., 1989b) and submitted for publication in Aviation, Space and Environmental Medicine.

B.3.3 Anaerobic Power Testing of Tactical Air Command Pilots. The WAT data from TAC fighter pilots were obtained to determine if our experimental subjects' anaerobic fitness levels represented the TAC population. Testing was discontinued in June 1988, when the TAC centrifuge training program was transferred from Brooks AFB, TX to Holloman AFB, NM.

### B.4 Standardization of Anthropometric Procedures

During this contract period, KRUG personnel developed procedures for obtaining anthropometric data and establishing a database to maintain thermal, altitude, and centrifuge test subject data. The database is used by VN investigators as a cost effective method in selecting subjects as well as in sizing equipment and garments. The recommended procedures have been adopted in the VN Operating Instruction 169-1, Human Subjects in Research, approved 15 December 1988.

To ensure data reliability, a 10-h training workshop was conducted during which a 50-min videotape was produced. The video, titled "Anthropometric Data Acquisition Workshop, March 1988," provides instruction for accurately taking

the 22 preselected body measurements using the anthropometric rig located in the USAFSAM/VNL Cockpit and Equipment Integration Laboratory (CEIL). The test subject data are located on the SAM780 VAX currently available through VNSC or VNL/CEIL. Development of user-friendly retrieval programs is continuing. A program within the USAFSAM Acceleration Repository (Sperry/Univac) will be used to retrieve the most recent anthropometric record for centrifuge test subjects per exposure.

#### B.5 High-G Training Database Research

The use of non-aircrew experimental subjects to enhance fighter pilot G-tolerance (e.g., by development of better anti-G suits), could be more effective if the subjects and pilots could be compared with respect to G-tolerance. Existing data in the High-G Training database and the USAF Coronary Artery Risk Evaluation database were merged to better define fighter pilot G-tolerance and to relate tolerance with physiologic/anthropometric parameters. The results of this study are presented in papers listed in Appendix IV-A by Fischer et al. and Webb et al. The raw data on the fighter pilots remains on the High-G Training database managed by the Crew Technology Division.

APPENDIX IV-A:

PUBLICATIONS/ABSTRACTS/REPORTS DOCUMENTING ANTI-G SUIT  
FABRICATION AND TESTING

Burton RR, Krutz RW, Boyce JB, Alexander WC. Human tolerance to two profiles for the crew emergency return vehicle (CERV). (Abstract) Aviat Space Environ Med 59:485(133) 1988.

Fischer JR Jr, Meeker LJ, Gillingham KK, Webb JT. Pilot reaction to high G stress on the human centrifuge. Proceedings of the 26th Annual SAFE Symposium, pp. 80-82, Las Vegas, NV, 1989.

Forster EM, Fischer JR Jr. The dream phenomena during GLOC. (Abstract) Aviat Space Environ Med 60:490(82) 1989.

Helms SJ, Bass GF, Jorgensen O, Daily WP. Limited qualitative evaluation of the advanced technology anti-G suits (ATAGS). USAFTPS-TR-88A-4. USAF Test Pilot School, Edwards AFB, CA, Dec 1988.

Krutz RW Jr, Burton RR, Forster EM. Physiologic correlates of protection from three types of anti-G suits. (Abstract) Aviat Space Environ Med 59:480(104) (1988b).

Krutz RW Jr, Burton RR, Forster EM. Physiologic correlates of protection afforded by anti-G suits. (In press) Aviat Space Environ Med.

Krutz RW Jr, Krueger AG, Burton RR. A comparison of uniform pressure anti-G suits. Proceedings of the 25th Annual SAFE Symposium, pp. 50-53, Las Vegas, NV, 1988a.

Scott WR, Simpson RE. The application of anthropometric data to the sizing of aircrew pressure protective G-garments. Proceedings of the 26th Annual SAFE Symposium, pp. 40-45, Las Vegas, NV, 1989.

Webb JT, Fischer JR Jr, Meeker LJ. High-G training results: Correlation with physiologic and anthropometric data. (Abstract) Aviat Space Environ Med 60:512(213) 1989.

Wiegman JF, Drew GA, Stranges SF. Measuring heart rate response to the Wingate cycle ergometer test. Proceedings of the 26th Annual SAFE Symposium, pp. 5-9, Las Vegas, NV, 1989a.

Wiegman JF, Krock LP, Burton RR, Forster EM. Anaerobic power testing and +G<sub>z</sub> endurance. (Abstract) Aviat Space Environ Med 60:512(214) 1989b.

Wiegman JF, Krock LP, Burton RR, Forster EM. The Wingate anaerobic test as an indicator of capacity for simulated aerial combat maneuvers. (In preparation for Aviat Space Environ Med )

PART V:  
ACCELERATION DATABASE

Bijan Eshaghian

A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Statement of Work (SOW) required the expansion, modification, and maintenance of a computerized database for data collection, storage, retrieval, and data manipulation to support the acceleration (ACC) repository.

B. ACCOMPLISHMENTS

B.1 Background

The ACC database was designed to collect information generated from the USAFSAM human centrifuge. The database contains results of 27,820 G-stress runs from 5,331 research exposures of 1,321 subjects at the USAF School of Aerospace Medicine (USAFSAM).

B.2 Procedures

The USAFSAM ACC repository is maintained on the SPERRY-UNIVAC 1100/81 mainframe computer under the EXEC 8 operating system. The root files "1ACCEL\_\_\_\_", "2ACCEL\_\_\_\_", "3ACCEL\_\_\_\_", "4ACCEL\_\_\_\_", "5ACCEL\_\_\_\_", "6ACCEL\_\_\_\_", "7ACCEL\_\_\_\_" and the supporting programs (which update the ACC database) were designed; they reside in a directory called "ACCEL" on Univac.

The principal software called "ACCEL.UPDATE" was modified from FIELD DATA COBOL to ASCII COBOL to update the data files transferred from the SAM70 system. The update program was also modified to store the numeric code for each narrative field.

A program called "ACCEL.ACC\_TEMP" was designed to validate the data after input to the repository.

Two procedures called "ACCEL.BACKUP" and "ACCEL.REVERT" were developed for recovery purposes in case the database is damaged.

The table look-up file called "B05ACCTB1" was modified to allow addition of new entries.

Documents to provide data entry record structure, and operational procedure are available and reside in the files with an extension of ".RNO" on the SAM70 system.

Publications and abstracts documenting results of acceleration database research can be found in Appendix V-A.

APPENDIX V-A:

PUBLICATIONS DOCUMENTING ACCELERATION DATABASE RESEARCH

- Eshaghian B, Forster EM, Fischer JR. Ten years of acceleration research. Proceedings of the 26th Annual SAFE Symposium, pp. 1-4, Las Vegas, NV, 1989.
- Eshaghian B, Lozano P. A computerized system for collecting and retrieving acceleration stress data. Proceedings of the 25th Annual SAFE Symposium, pp. 48-49, Las Vegas, NV, 1988.
- Forster EM, Whinnery JE. Aerobically trained individuals: Heart rate response to +G<sub>z</sub> stress. (Abstract) Aviat Space Environ Med 58:509(159) (1987).
- Forster EM, Whinnery JE. Reflex heart rate response to variable onset +G<sub>z</sub>. Aviat Space Environ Med 59:249-254 (1988).
- Whinnery JE. Acceleration tolerance of asymptomatic aircrew with mitral valve prolapse. Aviat Space Environ Med 57:986-992 (1986).
- Whinnery JE, Whinnery CE. Acceleration induced electrocardiographic interval changes. Aviat Space Environ Med 59:102-106 (1988).

## PART VI:

### CHEMICAL DEFENSE SHELTER PROCESSING

William R. Scott and Janet F. Wiegman

#### A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Chemical Defense Shelter Processing Task was undertaken for USAFSAM/VNC to provide the capability to perform long-term developmental tests for evaluating selected personal protective equipment (PPE) concepts. This task combined a series of experimental studies and a technical writing effort.

#### B. ACCOMPLISHMENTS

##### B.1 Technical Writing Task

Working from the raw experimental data, individual interim reports were written as USAF Technical Papers (TPs) on 1 to 2-wk experiments performed in the Survivable Collective Protection Shelter (SCPS-2B) test facility. Since many of these experiments employed the same equipment and procedures, much of the methodology was written as separate Appendixes, which could be included in all of the reports. Many of the reports also included unique appendixes in addition to those describing common methodology. Nine volumes of SCPS-2B technical papers were written under this part of the task assignment and are listed in R&D Status Report No. 41 (for the January 1989 reporting period).

Four papers and presentations concerning Chemical Defense Shelter Systems were also written under this task (Appendix VI-A; Scott and Simpson, 1988; Simpson, 1987; Simpson, 1989b; Simpson and Baumgardner, 1988).

##### B.2 Relationship Between Maximal Offgassing Booth Vapor Concentration and Transferred Simulant Mass

B.2.1 Objective. In a typical SCPS-2B study, personnel wearing CDE are exposed to chemical agent simulant, then processed into the toxic free area (TFA) of the SCPS-2B, where they immediately enter airtight offgassing booths. The relative effectiveness of a new CDE, don/doff procedure or shelter modification is determined by comparing the simulant (methyl salicylate) vapor concentrations in the offgassing booths with baseline data. The purpose of this study was to determine the relationship between the amount of simulant vapor offgassed by a subject and the recovery, which is the total amount of vapor in the booth (vapor concentration x volume of the booth). A detailed description of this study can be found in Scott and Simpson (1989a), (Appendix VI-A).

B.2.2 Accomplishments. The recovery varied from subject to subject and with the rate of evaporation of the methyl salicylate; the faster the rate of evaporation the greater the recovery. On average, 52% of the simulant mass that was evaporated in the occupied booths was recovered as a vapor. Therefore, a simple method to estimate the total amount of methyl salicylate offgassed from a subject is to double the maximum recovery in the offgassing booth.

A vented offgassing booth was designed by KRUG International and constructed by Rothe Development Corporation. The vented booth has been installed in the SCPS-2B TFA; the recovery of methyl salicylate using this booth will be measured in a future study.

B.3 Vapor Carry-Through into the Toxic Free Area (TFA) by Subjects Wearing Unwashed and Washed Chemical Defense Protective Garments

B.3.1 Objective. To accurately determine specific causes of increases in TFA vapor transport during shelter entry by initially contaminated personnel, it was necessary to determine whether the use of laundered CDE in USAFSAM/VNC vapor transfer studies leads to increased vapor transport. Four garments were evaluated; the ground crew CDE, the UK aircrew undercoveralls and the Von Blucher No. 2 and No. 7 undercoveralls. The details of these studies can be found in Simpson (1989c) (Appendix VI-A) and in the reports listed in Appendixes VI-B, C, D, and E.

B.3.2. Accomplishments. The results of these studies are summarized in Table VI-1, which lists the mean maximum offgassing booth vapor concentrations for the subjects wearing the unwashed and laundered test garment in each study, along with the garment evaluated.

TABLE VI-1. MEAN MAXIMAL BOOTH CONCENTRATION FOR THE UNWASHED/WASHED GARMENT STUDIES

Garment	Max Booth Conc (mg m <sup>-3</sup> )			Source (Appendix)
	Unwashed	2x	4x	
Ground Crew Overgarment	.053	.047	.084	VI-A (Simpson, 1989c)
UK Aircrew Undercoverall	.064	.095	-	VI-B
Von Blucher No. 7 U'coverall	.048	.061	-	VI-C
Von Blucher No. 2 U'coverall	.141	.159	-	VI-D
Ground Crew Overgarment	.042	.031	.077	VI-E

These results suggest that in USAFSAM chemical defense (CD) facility studies, where TFA vapor transfer determination is a test objective, the garments in the laundered state may be used without adverse influence on offgassing booth vapor concentration, although some discretion should be used. However, the 4-times-laundered garments yielded an average increase of 71% in maximum offgassed vapor concentration when compared with the unwashed garments; 4-times-laundered ground crew CDE should not be used in vapor transfer studies.



B.4. LHA Contamination During Entry Procedures of Initially Uncontaminated Subjects

B.4.1 Objective. Measurements of simulant vapor levels offgassed by a subject in an offgassing booth do not indicate whether the vapors are a result of the primary simulant challenge that was administered to the subject outside the SCPS-2B, or of the secondary contamination, the contamination that occurs during entry procedures through a contaminated LHA. Three separate week-long studies investigated the contribution of secondary contamination to the maximum vapor levels measured in the offgassing booths. Details of these studies can be found in the articles listed in Appendixes VI-F, VI-G, and VI-H.

B.4.2 Accomplishments. In all three studies, initially uncontaminated subjects did offgas vapors in the offgassing booths. In the two studies where uncontaminated subjects were processed with liquid contaminated subjects, the uncontaminated subjects had maximum booth concentrations (MBC) that were 26.5% and 13.4% of the contaminated subjects. In the study where uncontaminated subjects encountered a vapor in the LHA, the MBCs were directly related to the skin Ct ( $\text{mg m}^{-3} \text{ min}$ ) in the LHA,

$$\text{MBC} = -.0068 \text{ mg m}^{-3} + .0013 \text{ min}^{-1} \text{ Ct}$$

In conclusion, it is possible for an initially uncontaminated person to pick up secondary contamination while processing through a contaminated LHA.

B.5. TFA Vapor Carry-Through Comparison of Prototype CDEs with Regulation CDEs

B.5.1 Objective. At the request of USAFSAM/VNC, two studies were conducted to compare the TFA vapor carry-through of subjects wearing prototype CDEs with subjects wearing regulation CDEs. The two prototype CDEs studied were the ground crew CDE with a Von Blucher No. 2 undercoverall--worn underneath the fatigues which were the outer layer of the CDE--and an aircrew CDE that used the charcoal fabric CWU-66/P flight suit, instead of the UK charcoal undergarments. The details of the Von Blucher No. 2 study and the CWU-66/P study can be found in Appendix VI-A (Scott, 1989b). KRUG International also assisted USAFSAM/VNC in the thermal evaluation of the CWU-66/P flight suit (Appendix VI-A; Krock et al., 1988).

B.5.2 Accomplishments. The mean maximum offgassing booth concentrations for subjects wearing the different CDEs in these comparison studies are listed in Table 2 along with the form of the simulant (methyl salicylate) challenge.

TABLE VI-2. MEAN MAXIMUM OFFGASSING BOOTH CONCENTRATIONS

Prototype CDE	Challenge	Mean Maximum Booth Concentration ( $\text{mg m}^{-3}$ )	
		Prototype CDE	Regulation CDE
Von Blucher No. 2	liquid	0.128	.034
CWU-66/P	vapor	0.005	.003
CWU-66/P	liquid	0.040	.028

In both studies there was significantly more TFA vapor transfer with the prototype CDEs than with the regulation CDEs.

#### B.6 Evaluation of the Chemical Protection Capabilities of the Ground Crew CDE

B.6.1 Objective. Three separate studies measured the chemical protection capability of the ground crew CDE worn by subjects who performed light exercises. The preliminary study (Appendix VI-I) indicated that the two major sites of vapor penetration were underneath the hood skirt and at the junction of the CDE jacket and trousers. The next two studies examined these two sites of vapor penetration in more detail.

B.6.2 Accomplishments. Results of the final two studies can be found in Scott and Simpson (1989b) and Scott (1989a) (Appendix VI-A).

#### B.7 Evaluation of TAWC Entry/Exit Procedures In the SCPS-2B

B.7.1 Objective. A study was conducted to repeat elements of a USAF Tactical Air Warfare Center (USAF TAWC) test program to validate standard and refined ground crew chemical defense shelter entry and exit procedures. Details of the study can be found in Appendix VI-A (Simpson, 1987a).

B.7.2 Accomplishments. Data on TFA vapor carry-through, liquid transfer, and personnel entry and exit times showed no significant differences between the standardized and refined procedures. The refined procedures introduced both procedural and chemical safety problems. With the simulant test challenges used, subjects were exposed to excessive unprotected skin vapor dosages during both the standardized and refined procedures.

#### B.8 Interaction of Pyridostigmine Bromide with Mild Hypoxia and Rapid Decompression

B.8.1 Objective. The use of pyridostigmine bromide (PB) as a chemical warfare (CW) pre-treatment (prophylactic) drug was studied at operational altitudes and during rapid decompressions to determine if any adverse physiological changes and/or performance decrements occurred.

B.8.2 Accomplishments. In the dosages used in this study, PB did not appear to alter the normal physiological changes associated with moderate decreases in barometric pressure. Details of this study can be found in Krutz (1987a, b) (Appendix VI-A).

B.9 The Effect of Pyridostigmine Bromide on Acceleration Tolerance

B.9.1 Objective. In support of the human factors aspect of chemical defense protection and personal protective equipment (PPE) concepts, the effect of the pretreatment drug pyridostigmine bromide (PB) on acceleration tolerance was evaluated. It has been considered as a pre-exposure antidote to prevent potentially lethal effects of specific CW agents.

B.9.2 Accomplishments. Testing and data collection for this experiment was initiated and completed by Rothe Development under Contract Nos. F33615-81-D-0606 and F33615-85-D-4510. Human subjects were exposed to varying +G<sub>z</sub> profiles on the USAFSAM human centrifuge while ingesting either PB or placebo<sup>z</sup> in a double-blind experiment. The protocol was designed to detect any possible changes in acceleration tolerance, deficits in specific performance tasks, and peak plasma levels of PB and corresponding acetylcholinesterase inhibition (AChEI). Under the present contract, the resulting data were compiled, analyzed and submitted for publication (Whinnery, et al., 1989).

B.10 Physiological Assessment of Two Protective Garments for Chemical Warfare Casualties

B.10.1 Objective. The coveralls, ambulatory casualty chemical protection (CACCP), and a chemical protective litter-wrap were examined to determine the extent of induced hypoxia produced when wearing either garment and the extent of hypercapnia; i.e., CO<sub>2</sub> buildup.

B.10.2 Accomplishments. Details of this study can be found in Burton et al. (1987; Appendix VI-A).

APPENDIX VI-A:

PUBLICATIONS/ABSTRACTS DOCUMENTING  
CHEMICAL DEFENSE SHELTER PROCESSING RESEARCH

- Burton RR, Krutz RW Jr, Fagan ML. Physiological assessment of two protective garments for chemical warfare casualties. Sixth Medical Chemical Defense Bioscience Review Proceedings, Baltimore, MD, pp. 539-542, 1987. (Distribution authorized to U.S. Gov't agencies and their contractors; administrative/operational use; Aug 87. Other requests must be referred to Commander, U.S. Army Medical Research Institute of Chemical Defense, Attn: SGRD-UV-RC, Aberdeen Proving Ground, MD 21010-5425.)
- Krock L, Garza J, Wiegman J. Thermal evaluation of two prototype aircrew chemical defense ensembles. USAFSAM-TP-89-10, Aug 1989.
- Krutz RW Jr, Burton RR, Schiflett S, Holden R, Fisher JR Jr. Interaction of pyridostigmine bromide with mild hypoxia and rapid decompression. Sixth Medical Chemical Defense Bioscience Review Proceedings, Baltimore, MD, pp. 601-604, 1987a. (Distribution authorized to U.S. Gov't agencies and their contractors; administrative/operational use; Aug 87. Other requests must be referred to Commander, U.S. Army Medical Research Institute of Chemical Defense, Attn: SGRD-UV-RC, Aberdeen Proving Ground, MD 21010-5425.)
- Krutz R Jr, Burton R, Holden R, Fischer JR Jr. Physiologic effects of pyridostigmine bromide at ground level and altitude. (Abstract) Aviat Space Environ Med 58:509(160) (1987b).
- Scott WR, Pointer BW. An evaluation of the vapor protection capabilities of the jacket/trouser interface on the regulation ground crew CDE. USAFSAM-TP-89-13, (1989a) (In preparation).
- Scott WR, Simpson RE. Comparison of vapor transfer associated with collective protection entry of subjects wearing an aircrew Chemical Defense Ensemble (CDE) based on the CWU-66/P flight suit and the USAF regulation aircrew CDE. USAFSAM-TP-89-16, (1989b) (In preparation). (Distribution authorized to Department of Defense and DoD contractors only; critical technology; 22 November 1989. Other requests shall be referred to USAFSAM/TSKS (STINFO Officer).)
- Scott WR, Simpson RE. Relationship between the amount of methyl salicylate offgassed by subjects in sealed booths and the measured booth vapor levels. USAFSAM-TP-89-3, Oct 1989(a).
- Scott WR, Simpson RE. Evaluation of the vapor protection capabilities of the M-17 respirator/hood assembly on the USAF ground crew chemical defense ensemble. USAFSAM-TR-89-15, Oct 1989(b).

- Scott WR, Simpson RE. Evaluation of collective protection shelter systems. Proceedings of the 25th Annual SAFE Symposium, pp. 35-40, Las Vegas NV, 1988.
- Simpson RE. Mobile rest and relief facilities for use in a chemical warfare environment. USAFSAM-TP-89-15 (1989b) (In preparation).
- Simpson RE. An investigation of the effect of laundering the groundcrew chemical defense overgarment on toxic-free-area (TFA) vapor transfer during shelter entry by initially contaminated personnel. USAFSAM-TR-89-17 (1989c) (In preparation).
- Simpson RE, Baumgardner FW. Fixed base collective protection - validation criteria. NATO AGARD Meeting in Madrid, Spain, May, 1988. (Distribution authorized to U.S. Government agencies and their contractors; administrative/operational use; 29 April 1988. Other requests shall be referred to USAFSAM/TSKS (STINFO Officer).)
- Simpson RE. Chemical Defense-The individual protective equipment collective protection interface AFSC ASD NATO Conf. Proceedings, pp. 117-124. Williamsburg, VA, Sep, 1987b. (Distribution authorized to Department of Defense components and DOD contractors only; critical technology; 5 October 1987. Other requests shall be referred to USAFSAM/TSKS (STINFO Officer).)
- Whinnery JE, Burton RR, Parker FR Jr, Forster EM, Barber JA. The effects of pyridostigmine bromide on acceleration tolerance. (Abstract) Aviat Space Environ Med 60:504(161) 1989.

APPENDIX VI-B:  
VAPOR TRANSFER STUDY-COMPARISON OF WASHED AND UNWASHED  
AIRCREW CHEMICAL PROTECTIVE UNDERCOVERALLS (UK VERSION)

# KRUG INTERNATIONAL

27 May 1987

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Lt Col Page)  
Brooks AFB, TX 78235-5301

SUBJECT: Procedures And Test Results of USAFSAM/VNC Chemical  
Defense Facility Study No. 03-87-04 Conducted 9-12  
March 1987

STUDY TITLE: Vapor Transfer Study-Comparison of Washed and  
Unwashed Aircrew Chemical Protective Undercover-  
alls (UK Version)

FACILITY USED: USAFSAM/VNC SCPS-2B Facility

FACILITY AIRFLOW: 1200 cfm

AIRLOCK AIRFLOW: 350 cfm

SUBJECT AIRLOCK DWELL TIME: 2 min

NO. OF TEST SUBJECTS USED: 4

NO. OF TEST DAYS: 4

TFA OFFGASSING BOOTHS USED: Four booths used on each test day  
with each subject using each of the booths over the four test  
days. Subjects offgassed in the booths for 2 h on each test  
day.

BLACK LIGHT (UV) SCANNING: The four test subjects were UV scan-  
ned pretest and after exit from the offgassing booths.

SHELTER EXIT/ENTRY SEQUENCES: All subjects completed one exit-  
spray challenge-entry sequence on each day.

DON-DOFF PROCEDURES: Basically standard procedures, but with  
attendant assistance for doffing contaminated outer garments,  
doffing protective underoverall and gloves and for mask  
exchanges.

SIMULANT SPRAY CHALLENGE: Neat methyl-salicylate with Tinopal  
additive. Target dosage  $5 \text{ g m}^{-2}$  per subject.

SUBJECTS' TEST ENSEMBLE:

Chemical Protective Undercoverall-New-Unwashed and New-Washed Twice.

Fatigue Jacket and Trousers

\*Socks-Tube-Men's, White

\*T-Shirt-White

\*Jockey Shorts-White

Gloves-Set, CP, Groundcrew

Gloves, Insert-White

Boots-Flyers, FWU. 3/P

Overboot-CP

Mask CB Prot M17 + Hood

Plastic Bag Overboots.

\*These items worn by subjects on entry to TFA/Offgassing booths.

LOCATION OF SIMULANT VAPOR SAMPLERS:

LHA Overboot Don/Doff Area

LHA Changing Chute Area

LHA Mask Storage Area

VHA Mask Exchange Archway

VHA No. 1 Airlock Area

TFA Scanning Booth Area

TFA In Each Offgassing Booth

DECONTAMINATION: Test subjects used the fuller's earth spray booth on entry to the SCPS-2B Facility after being sprayed with CW agent simulant. Excess fuller's earth was removed by brushing on exit from the FE spray booth. Periodic cleaning of gloved hands also took place in the CCA during the entry/undressing procedures.



SUMMARY OF TEST RESULTS

LIQUID SIMULANT CHALLENGE TO TEST SUBJECTS

Test Subject No.	Methyl Salicylate Dosage To Subject $\text{g m}^{-2}$				Mean
	Day 1	Day 2	Day 3	Day 4	
01	6.99	4.54	6.44	6.48	6.11
02	5.89	4.45	7.28	5.40	5.76
03	5.36	5.57	4.90	5.91	5.44
04	6.50	4.06	3.91	4.55	4.76
Mean:	6.19	4.66	5.63	5.59	5.52

Mean dosage, washed garment subjects,  $5.58 \text{ g m}^{-2}$   
Mean dosage, unwashed garment subjects,  $5.45 \text{ g m}^{-2}$

RECORDED DAILY MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
(CORRECTED FOR RESIDUAL BACKGROUND)

Test Day	Offgassing Booth Max. Vapor Conc'n $\text{mg m}^{-3}$	
	Unwashed U'Overall Subjects	Washed U'Overall Subjects
1	0.080	0.132
2	0.057	0.082
3	0.046	0.085
4	0.076	0.081
Mean:	0.064	0.095

SUBJECT SPECIFIC MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
(CORRECTED FOR RESIDUAL BACKGROUND)

Subject Ser No.	Offgassing Booth Max. Vapor Concentration $\text{mg m}^{-3}$		
	Unwashed Undercoverall	Washed Undercoverall	Overall Mean
01	0.050	0.099	0.075
02	0.060	0.096	0.078
03	0.086	0.067	0.077
04	0.062	0.118	0.090

MAXIMUM RECORDED SIMULANT VAPOR CONCENTRATIONS  
IN THE TEST FACILITY DURING TEST  
MAXIMUM VAPOR CONCENTRATION  $m^{-3}$

Test Day No.	LHA Overboot Change Area	LHA Change Chutes (Max of 3)	LHA Mask Storage Area	VHA Mask Exchange Area	VHA No. 1 Airlock Area	TFA Scanning Booth Area
1	7.431	5.852	4.633	0.232	0.176	0.002
2	7.348	6.439	3.314	0.110	0.080	-
3	4.102	5.740	3.967	0.097	0.077	0.001
4	4.186	4.273	3.152	0.095	0.113	0.002

BLACKLIGHT (UV) SCANNING OF TEST SUBJECTS: The post-test UV scanning produced no evidence of liquid simulant transfer to their skin or underwear assembly over the four test days.

OBSERVATIONS AND CONCLUSIONS: The simulant dosage applied to the test subjects,  $5.58 \text{ g m}^{-2}$  -washed garment and  $5.45 \text{ g m}^{-2}$  -unwashed garment, was very close to the target dosage of  $5.0 \text{ g m}^{-2}$ .

The mean maximum offgassed vapor concentration for the washed-garment subjects ( $0.095 \text{ mg m}^{-3}$ ) was 48% higher than for the unwashed-garment subjects ( $0.064 \text{ mg m}^{-3}$ ).

These study findings indicate that discretion should be used in the use of washed Chemical Protective Aircrew Undercoveralls (UK-Type) in future USAFSAM/VNC studies where vapor transfer determination is a primary objective.

Robert E. Simpson  
Research Engineer

/vbj

APPENDIX VI-C:

VAPOR TRANSFER STUDY-COMPARISON OF WASHED AND UNWASHED  
VON BLUCHER CHEMICAL PROTECTIVE UNDERCOVERALLS (TYPE 7)

# KRUG INTERNATIONAL

23 June 1987

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Lt Col Page)  
Brooks AFB, TX 78235-5301

SUBJECT: Outline Procedures And Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 06-87-09 Conducted  
8-11 June 1987

STUDY TITLE: Vapor Transfer Study-Comparison of Washed and  
Unwashed Von Blucher Chemical Protective Under-  
coveralls (Type 7)

FACILITY USED: USAFSAM/VNC SCPS-2B Facility

FACILITY AIRFLOW: 1200 cfm

AIRLOCK AIRFLOW: 350 cfm

SUBJECT AIRLOCK DWELL TIME: 2 min

NO. OF TEST SUBJECTS USED: 4

NO. OF TEST DAYS: 4

TFA OFFGASSING BOOTHS USED: Four booths used on each test day  
with each subject using each of the booths over the four test  
days. Subjects offgassed in the booths for 2 h on each test  
day.

BLACK LIGHT (UV) SCANNING: The four test subjects were UV scan-  
ned pretest and after exit from the offgassing booths.

SHELTER EXIT/ENTRY SEQUENCES: All subjects completed one exit-  
spray challenge-entry sequence on each day.

DON-DOFF PROCEDURES: Basically standard procedures, but with  
attendant assistance for doffing contaminated outer garments,  
doffing protective underoverall and gloves and for mask  
exchanges.

SIMULANT SPRAY CHALLENGE: Neat methyl salicylate with Tinopal additive.  
Target dosage 5 g m<sup>-2</sup> per subject.

SUBJECTS' TEST ENSEMBLE:

Von Blucher (No. 7) Chemical Protective Undercoverall-New-Unwashed  
and New-Washed Twice.

Fatigue Jacket and Trousers

\*Socks-Tube-Men's, White

\*T-Shirt-White

\*Jockey Shorts-White

Gloves-Set, CP, Groundcrew

Gloves, Insert-White

Boots-Flyers', FWU. 3/P

Overboot-CP

Mask CB Prot M17 + Hood

Plastic Bag Overboots

\*These items worn by subjects on entry to TFA/Offgassing booths.

LOCATION OF SIMULANT VAPOR SAMPLERS:

LHA Overboot Don/Doff Area

LHA Changing Chute Area

LHA Mask Storage Area

VHA Mask Exchange Archway

VHA No. 1 Airlock Area

TFA Scanning Booth Area

TFA In Each Offgassing Booth

DECONTAMINATION: Test subjects used the fuller's earth spray booth on entry to the SCPS-2B Facility after being sprayed with CW agent simulant. Excess fuller's earth was removed by brushing on exit from the FE spray booth. Periodic cleaning of gloved hands also took place in the CCA during the entry/undressing procedures.

SUMMARY OF TEST RESULTS

LIQUID SIMULANT CHALLENGE TO TEST SUBJECTS

Test Subject No.	Methyl Salicylate Dosage To Subject $g\ m^{-2}$				Mean
	Day 1	Day 2	Day 3	Day 4	
01	3.874	3.865	3.489	5.416	4.161
02	3.673	4.097	3.470	2.355	3.399
03	3.258	3.414	5.299	3.790	3.940
04	4.538	3.151	4.394	5.257	4.335
Mean:	3.836	3.632	4.163	4.205	3.959

Mean dosage, washed garment subjects,  $4.182\ g\ m^{-2}$   
 Mean dosage, unwashed garment subjects,  $3.736\ g\ m^{-2}$

RECORDED DAILY MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
 (CORRECTED FOR RESIDUAL BACKGROUND)

Test Day	Offgassing Booth Max. Vapor Conc'n $mg\ m^{-3}$	
	Unwashed U'Coverall Subjects	Washed U'Coverall Subjects
1	0.039	0.055
2	0.043	0.076
3	0.049	0.050
4	0.059	0.064
Mean:	0.048	0.061

SUBJECT SPECIFIC MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
(CORRECTED FOR RESIDUAL BACKGROUND)

Subject Ser No	Offgassing Booth Max. Vapor Concentration $\text{mg m}^{-3}$		Overall Mean
	Unwashed Underoverall	Washed Underoverall	
01	0.041	0.047	0.044
02	0.048	0.079	0.064
03	0.041	0.066	0.054
04	0.060	0.052	0.056

DETAILS OF TEST SUBJECTS:

Subject No.	Age	Height (in)	Weight (lb)	M/F
01	32	62.5	184	F
02	26	70.5	202	M
03	20	67.5	138	M
04	43	63.0	134	F

MAXIMUM RECORDED SIMULANT VAPOR CONCENTRATIONS  
IN THE TEST FACILITY DURING TEST  
(CORRECTED FOR RESIDUAL BACKGROUND)

Test Day No.	LHA Overboot Change Area	Recorded Max. Vapor concentration $\text{mg m}^{-3}$				TFA Scanning Booth Area
		LHA Change Chute	LHA Mask Storage Area	VHA Mask Exchange Area	VHA No. 1 Airlock Area	
1	5.536	6.253	4.332	0.014	0.008	0.002
2	7.342	10.189	6.322	0.011	0.006	0.002
3	8.000	9.687	5.949	0.008	0.009	0.002
4	10.247	11.724	5.877	0.012	0.008	0

BLACKLIGHT (UV) SCANNING OF TEST SUBJECTS: The UV scanning of the test subjects, post-test, indicated that two subjects had sustained contaminant transfer to a hand on Test Day 1. Apparent transfer to the wrists of 2 subjects on Test Day 3 was subsequently shown to have been due to fluorescent "dressing" on the elasticated thumb-loops of the Von Blucher underoverall.

OBSERVATIONS AND CONCLUSIONS: The mean simulant dosage applied to the test subjects,  $4.182 \text{ g m}^{-2}$ -washed garments and  $3.736 \text{ g m}^{-2}$ -unwashed garments, was less than the planned target dosage of  $5 \text{ g m}^{-2}$ .

The mean maximum offgassed vapor concentration for the washed-garment subjects ( $0.061 \text{ mg m}^{-3}$ ) was 27.1% higher than for the unwashed-garment subjects ( $0.048 \text{ mg m}^{-3}$ ).

These study findings suggest that discretion should be used in the use of washed Von Blucher (No. 7) Chemical Protective Undercoveralls in future USAFSAM/VNC studies where vapor transfer determination is a primary objective.

Robert E. Simpson  
Senior Research Engineer

/vbj



APPENDIX VI-D:

VAPOR TRANSFER STUDY-COMPARISON OF WASHED AND UNWASHED  
VON BLUCHER (NO. 2) CHEMICAL PROTECTIVE UNDERCOVERALLS

# KRUG INTERNATIONAL

4 May 1988

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Dr Luskus)  
Brooks AFB, TX 78235-5301

Subject: Outline Procedures And Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 07-87-10 Conducted  
6-9 July 1987

Study Title: Vapor Transfer Study-Comparison of Washed and  
Unwashed Von Blucher (No. 2) Chemical Protective Undercoveralls

Facility Used: USAFSAM/VNC SCPS-2B Facility

Facility Airflow: 1200 cfm

Airlock Airflow: 350 cfm

Subject Airlock Dwell Time: 2 min

No. of Test Subjects Used: 4

No. of Test Days: 4

TFA Offgassing Booths Used: Four booths used on each test day  
with each subject using each of the booths over the four test  
days. Subjects offgassed in the booths for 2 h on each test  
day.

Black Light (UV) Scanning: The four test subjects were UV  
scanned pretest and after exit from the offgassing booths.

Shelter Exit/Entry Sequences: All subjects completed one  
exit-spray challenge-entry sequence on each day.

Don-Dooff Procedures: Basically standard procedures, but with  
attendant assistance for doffing contaminated outer garments,  
doffing protective underoverall and gloves and for mask  
exchanges.

Simulant Spray Challenge: Neat methyl-salicylate with Tinopal additive.  
Target dosage  $5 \text{ g m}^{-2}$  per subject.

Subjects' Test Ensemble:

Von Blucher (No. 2) Chemical Protective Undercoverall-New-Unwashed and New-Washed Twice.

Fatigue Jacket and Trousers

\*Socks-Tube-Men's, White

\*T-Shirt-White

\*Jockey Shorts-White

Gloves-Set, CP, Groundcrew

Gloves, Insert-White

Boots-Flyers', FWU. 3/P

Overboot-CP

Mask CB Prot M17 + Hood

Plastic Bag Overboots

\*These items worn by subjects on entry to TFA/Offgassing booths.

Location of Simulant Vapor Samplers:

LHA Overboot Don/Doff Area

LHA Changing Chute Area

LHA Mask Storage Area

VHA Mask Exchange Archway

VHA No. 1 Airlock Area

TFA Scanning Booth Area

TFA In Each Offgassing Booth

Decontamination: Test subjects used the fuller's earth spray booth on entry to the SCPS-2B Facility after being sprayed with CW agent simulant. Excess fuller's earth was removed by brushing on exit from the FE spray booth. Periodic cleaning of gloved hands also took place in the CCA during the entry/undressing procedures.

Summary Of Test Results

LIQUID SIMULANT CHALLENGE TO TEST SUBJECTS

Test Subject No.	Methyl Salicylate Dosage To Subject $g\ m^{-2}$			
	Day 1	Day 2	Day 3	Day 4
01	5.219	3.775	3.455*	5.139*
02	4.040*	3.805*	3.246	4.596
03	5.065	4.575	3.553*	7.880*
04	4.394*	4.619*	3.189	4.423
Mean:	4.775	4.194	3.777	5.510

Mean dosage, washed garment subjects,  $4.261\ g\ m^{-2}$   
Mean dosage, unwashed garment subjects,  $4.611\ g\ m^{-2}$

\*Indicates unwashed garment

RECORDED DAILY MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
(CORRECTED FOR RESIDUAL BACKGROUND)

Test Day	Offgassing Booth Max. Vapor Concn $mg\ m^{-3}$	
	Unwashed U'Coverall Subjects	Washed U'Coverall Subjects
1	0.161	0.139
2	0.172	0.175
3	0.088	0.131
4	0.143	0.191
Mean	0.141	Mean 0.159

SUBJECT SPECIFIC MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
(CORRECTED FOR RESIDUAL BACKGROUND)

Subject Ser. No.	Offgassing Booth Max. Vapor Concentration $\text{mg m}^{-3}$		
	Unwashed Undercoverall	Washed Undercoverall	Overall Mean
01	0.209	0.175	0.192
02	0.105	0.170	0.138
03	0.124	0.146	0.135
04	0.126	0.143	0.135

Details of Test Subjects:

Subject No.	Age	Height (in)	Weight (lb)	M/F
01	32	63	187	F
02	42	63	133	F
03	23	68	183	M
04	20	67	133	M

MAXIMUM RECORDED SIMULANT VAPOR CONCENTRATIONS  
IN THE TEST FACILITY DURING TEST  
(CORRECTED FOR RESIDUAL BACKGROUND)

Test Day No.	Recorded Max. Vapor Concentration $\text{mg m}^{-3}$					
	LHA Overboot Change Area	LHA Change Chute	LHA Mask Storage Area	VHA Mask Exchange Area	VHA No. 1 Airlock Area	TFA Scanning Booth Area
1	8.905	10.526	5.161	0.012	0.011	0.002
2	7.421	10.749	6.576	0.027	0.018	0.000
3	8.052	12.022	7.156	0.016	0.019	0.000
4	8.783	11.413	6.311	0.030	0.024	0.004

Blacklight (UV) Scanning Of Test Subjects: The post-test UV scanning of the test subjects, indicated that on Day 1 Subject 01 sustained one liquid hit on each hand; on Day 3 Subject 02 sustained two liquid hits on each hand; and on Day 4, Subject 02 sustained one liquid hit on each hand and two liquid hits on the face.

Observations and Conclusions: The mean simulant dosage applied to the test subjects,  $4.261 \text{ g m}^{-2}$  (washed garments) and  $4.611 \text{ g m}^{-2}$  (unwashed garments), was less than the planned target dosage of  $5 \text{ g m}^{-2}$ .

The mean maximum offgassed vapor concentration for the washed-garment subjects ( $0.159 \text{ mg.m}^{-3}$ ) was 12.8% higher than for the unwashed-garment subjects ( $0.141 \text{ mg.m}^{-3}$ ).

These findings indicate that the Von Blucher No. 2 Chemical Protective Undercoverall provides subjects with less protection from vapor than garments evaluated in previous studies. The following table shows the mean maximum booth concentration of subjects wearing different types of unwashed and washed garments. The maximum booth concentrations of subjects wearing unwashed Von Blucher No. 2 undercoveralls are at least 100% greater than the maximum booth concentrations of the other unwashed garments. The maximum booth concentration produced by subjects wearing the washed Von Blucher No. 2 was at least 67% higher than any of the other washed garments. The vapor protection characteristics of the unwashed and washed Von Blucher No. 2 undercoverall are suspect.

MEAN MAXIMUM BOOTH CONCENTRATIONS OF  
SUBJECTS WEARING UNWASHED & WASHED  
GARMENTS IN PREVIOUS STUDIES

Study No.	Garment	Max. Booth Conc ( $\text{mg m}^{-3}$ )	
		Unwashed	Washed
1-87-03	Ground Crew Overgarment	.068	.066
3-87-04	U.K. Aircrew Undercoverall	.064	.095
6-87-09	Von Blucher No. 7 Undercoverall	.048	.061
7-87-10	Von Blucher No. 2 Undercoverall	.141	.159

William R. Scott  
Research Engineer

/vbj

APPENDIX VI-E:  
VAPOR TRANSFER STUDY-COMPARISON OF WASHED AND UNWASHED  
CHEMICAL DEFENSE GROUND CREW ENSEMBLES

# KRUG INTERNATIONAL

20 April 1988

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Dr. Luskus)  
Brooks AFB, TX 78235-5301

Subject: Outline Procedures And Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 02-88-17 Conducted  
22-26 Feb 88 and 29 Feb - 3 Mar 88

Study Title: Vapor Transfer Study-Comparison of Washed and  
Unwashed Chemical Defense Ground Crew Ensembles.

Facility Used: USAFSAM/VNC SCPS-2B Facility

Facility Airflow: 1200 cfm

Airlock Airflow: 350 cfm

Subject Airlock Dwell Time: 2 min

No. of Test Subjects Used: 4

No. of Test Days: 8

TFA Offgassing Booths Used: Four booths used on each test day  
with each subject using each of the booths over the four test  
days. Subjects offgassed in the booths for 2 h on each test  
day.

Black Light (UV) Scanning: The four test subjects were UV  
scanned pretest and after exit from the offgassing booths.

Shelter Exit/Entry Sequences: Subjects did not perform exit  
procedures. All subjects completed one spray challenge-entry  
sequence on each day.



Don-Off Procedures: Subjects donned their ensembles outside the SPCS-2B. Entry into the SPCS-2B and movements in the LHA during entry procedures were coordinated with the 5-min cycles of the impinger tubes in Changing Chute No. 3. The following table lists the schedule that each subject followed during the spraying and entry procedures.  $I_{sn}$  is the cycle number that a particular subject was sprayed (sn = subject number). The  $I_{sn}$ s were incremented by 1 cycle for each subject ( $I_{sn} = 6$  for 1st subject,  $I_{sn} = 7$  for 2nd subject, etc.).

<u>C.C. No. 3</u> <u>Impinger Cycle</u>	<u>Subjects</u> <u>Running Time</u>	<u>Subject</u> <u>Location</u>
$I_{sn}$	0-5:00	Spray booth
$I_{sn} + 1$	5:01-10:00	Decon. Annex
$I_{sn} + 2$	10:01 - 15:00	LHA Overboot Changing Area
$I_{sn} + 3$	15:01 - 18:00	LHA C.C. No. 3
$I_{sn}$	18:01 -	LHA C.C. No. 3

The LHA attendant helped subjects remove their CDE jacket and trousers. Once the CDE was removed, subjects performed the remaining entry procedures as rapidly as possible. The LHA and VHA attendants assisted the subject with the mask exchange.

Once in the TFA, subjects immediately entered an offgassing booth. After the booth door was closed, the TFA attendant started the impinger sampler system (30-min cycle times).

Simulant Spray Challenge: Neat methyl salicylate with Tinopal additive. Target dosage  $5 \text{ g m}^{-2}$  per subject.

Simulant LHA Vapor Challenge: Thirty-six gm of methyl-salicylate were poured on 2 sets of fatigues 15 min before the first subject entered the LHA. The contaminated fatigues were hung on the second level of racks (4 ft high) on the outside wall approximately 4 ft from the LHA/VHA wall.

Subjects' Test Ensemble:

Fatigue Jacket and Trousers, New (unwashed, washed twice or washed four times)

\*Socks-Tube-Men's, White

\*T-Shirt-White

\*Jockey Shorts-White

Gloves-Set, CP, Groundcrew

Gloves, Insert-White

Boots-Flyer's, FWU. 3/P

Overboot-CP

Mask CB Prot M17 + Hood

Plastic Bag Overboots

\*These items worn by subjects on entry to TFA/Offgassing booths.

Location of Simulant Vapor Samplers:

LHA Overboot Don/Doff Area (Pump No. 1)

LHA Changing Chute No. 3 (Pump No. 2)

LHA Mask Storage Area (Pump No. 5)

VHA Mask Exchange Archway (Pump No. 6)

Center of VHA (Pump No. 7)

TFA Scanning Booth Area (Pump No. 9)

TFA In Each Offgassing Booth (Pump No. 11, Booth 1; No. 12, Booth 2; No. 13, Booth 3; and No. 14, Booth 4)

Decontamination: Subjects were dusted with fuller's earth by an attendant in the SCPS-3 LHA. Excess fuller's earth was brushed off by the attendant.

Summary Of Test Results:

LIQUID SIMULANT CHALLENGE TO TEST SUBJECTS  
METHYL SALICYLATE DOSAGE TO SUBJECT  $\text{g m}^{-2}$

Test Day	Subject No.			
	01	02	03	04
1	3.228	3.818*	2.501	2.098*
2	3.948	3.710*	2.667	1.783*
3	2.945*	3.378	2.517*	1.948
4	2.026*	2.716	0.881*	1.385
5	3.616	7.405**	3.528	3.496**
6	0.659	0.924**	1.293	1.133**
7	2.886**	3.106	1.974**	1.355
8	1.332**	1.562	1.952**	1.178
Subject Means	2.580	3.32	2.164	1.797

Mean dosage, subjects with unwashed garments,  $2.379 \text{ gm m}^{-2}$

Mean dosage, subjects with garments washed two-times,  $2.472 \text{ gm m}^{-2}$

Mean dosage, subjects with garments washed four-times,  $2.638 \text{ gm m}^{-2}$

\*Subjects wore CDE garments that were washed twice

\*\*Subjects wore CDE garments that were washed four times.

SUBJECTS DAILY MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
 (CORRECTED FOR RESIDUAL BACKGROUND)

Test Day	Subject			
	01	02	03	04
1	.016	.010*	.021	.011*
2	.044	.014*	.032	.027*
3	.060*	.016	.036*	.025
4	.055*	.028	.029*	.022
Mean (Days 1-4)	<u>.044</u>	<u>.017</u>	<u>.030</u>	<u>.021</u>
5	.068	.086**	.141	.162**
6	.072	.070**	.042	.031**
7	.039**	.062	.098**	.036
8	.071**	.018	.054**	.029
Mean (Days 5-8)	<u>.063</u>	<u>.059</u>	<u>.084</u>	<u>.071</u>

\*Subjects wore CDE garments that were washed twice  
 \*\*Subjects wore CDE garments that were washed four times.

DAILY MAXIMUM OFFGASSING BOOTH VAPOR  
 CONCENTRATIONS - WASHED VS. UNWASHED  
 (CORRECTED FOR RESIDUAL BACKGROUND)

Test Day	Subjects With Unwashed-CDE Garment	Subjects With Washed-CDE Garment (Two Times)
1	.019	.011
2	.036	.021
3	.021	.048
4	.025	.042
Means (Days 1-4)	<u>.025</u>	<u>.031</u>

Test Day	Subjects With Unwashed-CDE Garment	Subjects With Washed-CDE Garment (Four Times)
5	.105	.124
6	.057	.051
7	.049	.069
8	.024	.063
Means (Days 5-8)	<u>.059</u>	<u>.077</u>

SUBJECT SPECIFIC MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
 (CORRECTED FOR RESIDUAL BACKGROUND)

<u>Test Subject</u>	<u>Days 1-4 Unwashed</u>	<u>Washed Twice</u>
01	.030	.058
02	.022	.012
03	.026	.033
04	.024	.019
Means	<u>.026</u>	<u>.031</u>

<u>Test Subject</u>	<u>Days 5-8 Unwashed</u>	<u>Washed Four Times</u>
01	.070	.055
02	.040	.078
03	.092	.076
04	.033	.097
Means	<u>.059</u>	<u>.077</u>

---

DETAILS OF TEST SUBJECTS

<u>Subject No.</u>	<u>Age</u>	<u>Height (in)</u>	<u>Weight (lb)</u>	<u>M/F</u>
01	20	67.5	137	M
02	33	68.5	168	M
03	39	68.5	146.5	M
04	33	62.5	178	F

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MAXIMUM RECORDED SIMULANT VAPOR CONCENTRATIONS  
 IN THE SCPS-2B DURING TRIAL ( $\text{mg m}^{-2}$ )  
 (CORRECTED FOR RESIDUAL BACKGROUND)

Test Day No.	LHA Overboot Change Area	LHA Change Chute No. 3	LHA Mask Storage Area	VHA Mask Exchange Area	VHA Center	TFA Scanning Booth Area
1	4.503	2.628	.461	.005	.000	.000
2	6.495	3.533	.954	.012	.004	.000
3	6.778	4.007	.881	.007	.005	.000
4	4.561	3.129	.858	.007	.003	----
5	14.754	6.179	1.891	.019	.020	.000
6	3.185	2.359	.849	.007	.004	.001
7	5.367	4.308	1.451	.013	.006	.000
8	4.281	.796	.731	.007	.001	.001

Blacklight (UV) Scanning Of Test Subjects: The UV scanning of the test subjects, post-test, showed that on Day 1, Subject No. 04 sustained liquid contamination on the hand; on Day 2, Subject No. 02 had liquid contamination on the hand and Subject No. 03 on the neck; and on Day 8, Subject No. 04 had liquid contamination on the neck.

Observations and Conclusions: The mean simulant dosage applied to the test subjects of  $2.47 \text{ gm m}^{-2}$  was less than the planned dosage of  $5.00 \text{ gm m}^{-2}$ .

The mean maximum offgassing booth vapor concentration with subjects that wore CDE garments that were washed two times ( $.031 \text{ mg m}^{-3}$ ) was 19% greater than the vapor concentrations generated by subjects that wore new unwashed CDE garments ( $.026 \text{ gm m}^{-3}$ ). The mean maximum offgassing booth vapor concentration for subjects that wore CDE garments washed four times ( $.077 \text{ gm m}^{-3}$ ) was 31% greater than the vapor concentration generated by subjects that wore new unwashed CDE garments ( $.059 \text{ gm m}^{-3}$ ).

The study findings suggest that discretion should be used in the use of washed CDE in USAFSAM/VNC studies where vapor transfer into a TFA is being measured.

William R. Scott, Ph.D.  
 Research Engineer

/vbj

APPENDIX VI-F:  
VAPOR TRANSFER STUDY-SPRAYED AND UNSPRAYED SUBJECT COMPARISON

# KRUG INTERNATIONAL

17 September 1987

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Dr. L. Luskus)  
Brooks AFB, TX 78235-5301

Subject: Outline Procedures And Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 08-87-12 Conducted  
3-6 August 1987

Study Title: Vapor Transfer Study-Sprayed and Unsprayed Subject  
Comparison.

Facility Used: USAFSAM/VNC SCPS-2B Facility

Facility Airflow: 1800 cfm

Airlock Airflow: 600 cfm

Subject Airlock Dwell Time: 2 min

No. of Test Subjects Used: 6

No. of Test Days: 4

TFA Offgassing Booths Used: Four booths used on each test day  
with Subjects 03, 04, 05, and 06 using each booth over the 4  
test days. Subjects remain in booths for 2 h.

Black Light (UV) Scanning: Subjects 01 and 02 are scanned on  
TFA entry. Subjects 03, 04, 05 and 06 are scanned on exit from  
offgassing booths.

Shelter Exit/Entry Sequences: Subjects exit TFA in numerical  
order at 60 sec intervals. After spraying, subjects enter the  
LHA, VHA and TFA in numerical order.

Don-Dooff Procedures: Basically standard procedures but with  
attendant assistance for doffing contaminated outer garments,  
doffing protective underoverall and gloves and for mask  
exchanges.



Simulant Spray Challenge: Neat methyl salicylate with Tinopal additive.  
Subjects 01, 02, 03 and 04 were sprayed with a target dosage of  $5 \text{ g m}^{-2}$ .  
Subjects 05 and 06 were not sprayed.

Subjects' Test Ensemble:

Chemical Protective Undercoverall-New-Unwashed

Fatigue Jacket and Trousers

\*Socks-Tube-Men's, White

\*T-Shirt-White

\*Jockey Shorts-White

Gloves-Set, CP, Groundcrew

Gloves, Insert-White

Boots-Flyers', FWU. 3/P

Overboot-CP

Mask CB Prot M17 + Hood

Plastic Bag Overboots

\*These items worn by subjects on entry to TFA/offgassing booths.

Location of Simulant Vapor Samplers:

LHA Overboot Don/Doff Area

LHA Changing Area, Chute 1

LHA Changing Area, Chute 2

LHA Changing Area, Chute 3

LHA Mask Storage Area

VHA Mask Exchange Archway

VHA No. 1 Airlock Area

TFA Scanning Booth Area

TFA In Each Offgassing Booth

Decontamination: Test subjects used the fuller's earth spray booth on entry to the SCPS-2B Facility after being sprayed with CW agent simulant. Excess fuller's earth was removed by brushing on exit from the FE spray booth. Periodic cleaning of gloved hands also took place in the CCA during the entry/undressing procedures.

Summary Of Test Results:

LIQUID SIMULANT CHALLENGE TO TEST SUBJECTS\*

Test Subject No.	Methyl Salicylate Dosage To Subject $\text{g m}^{-2}$			
	Day 1	Day 2	Day 3	Day 4
01	6.250	4.520	4.623	5.070
02	4.879	4.597	4.14	3.992
03	3.782	4.482	4.194	3.617
04	3.539	4.355	4.499	4.701
Mean:	4.613	4.489	4.365	4.345

\*Subjects 05 and 06 were not sprayed.

RECORDED DAILY MAXIMUM OFFGASSING BOOTH VAPOR CONCENTRATIONS  
(CORRECTED FOR RESIDUAL BACKGROUND)

Offgassing Booth Max. Vapor Conc'n  $\text{mg m}^{-3}$

Test Subj. No.	Test Day				Mean + 1S.D. By Subject	Mean + 1S.D. By Group
	1	2	3	4		
03*	.028	.030	.038	.028	.031 + .005	.0336 + .009*
04*	.045	.018	.045	.037	.036 + .013	
05**	.017	.011	.007	.011	.012 + .004	.0094 + .009**
06**	.005	.009	.009	.006	.007 + .002	
Mean	.024	.017	.025	.021		

\*Subjects 03 and 04 were sprayed

\*\*Subjects 05 and 06 were not sprayed

MAXIMUM RECORDED SIMULANT VAPOR CONCENTRATIONS  
IN THE TEST FACILITY DURING TEST  
MAXIMUM VAPOR CONCENTRATION mg m<sup>-3</sup>

Test Day No.	LHA Overboot Change Area	LHA Change Chute No. 1	LHA Change Chute No. 2	LHA Change Chute No. 3	LHA Mask Storage Area	VHA Mask Exchange Area	VHA No. 1 Airlock Area	TFA Scanning Booth Area
1	3.695	1.681	3.493		1.252	.015	.007	.000
2	6.782	3.199	3.423	.949	1.045	.012	.007	.001
3	7.436	2.115	5.453	.787	.954	.007	.003	.000
4	6.042	3.977	6.302	1.005	.752	.012	.008	.000

Blacklight (UV) Scanning Of Test Subjects: The UV scanning of the test subjects, post-test, showed liquid contamination of Subject 05's left hand on the third day of the trial. There was no evidence of liquid simulant transfer to the skin or underwear assembly of the other five subjects over the four test days.

Observations: The average simulant dosage applied to the test subjects, 4.453 g m<sup>-2</sup> was close to the target dosage of 5.0 g m<sup>-2</sup>.

On the third day of the trial, Subject 05 (unsprayed subject) picked up liquid contamination on the left hand, but his offgassing booth concentration for that day was less than on the other three days.

The mean maximal offgassing concentration of the unsprayed pair (Subjects 05 and 06) was statistically different from zero (P-value <.001), indicating that the unsprayed group picked up vapor while processing through the LHA or VHA.

The mean maximal offgassing vapor concentrations for the unsprayed pair was 28% of the mean maximal concentrations measured in the booths that contained the sprayed pair. The two means were statistically different (P-value <.001).

William R. Scott, Ph.D.  
Research Engineer

/vbj

APPENDIX VI-G:  
VAPOR TRANSFER STUDY-VAPOR CARRY-THROUGH DURING STANDARD  
SHELTER ENTRY PROCEDURES BY INITIALLY UNCONTAMINATED SUBJECTS

# KRUG INTERNATIONAL

22 February 1989

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Dr. L. Luskus)  
Brooks AFB, TX 78235-5301

SUBJECT: Outline Procedures and Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 10-87-15 Conducted  
5-8 October 1987

STUDY TITLE: Vapor Transfer Study-Vapor Carry-through During  
Standard Shelter Entry Procedures By Initially Uncontaminated  
Subjects.

FACILITY USED: SCPS-2B

FACILITY AIRFLOW: 1800 cfm

AIRLOCK AIRFLOW: 600 cfm

SUBJECT AIRLOCK DWELL TIME: 2 min

NO. OF TEST SUBJECTS USED: 4

NO. OF TEST DAYS: 4

TFA OFFGASSING BOOTHS USED: Four booths used on each test day.  
Subjects used a different booth each day of trial. Subjects off-  
gassed in booth for 1 hr.

BLACK LIGHT (UV) SCANNING: Not used.

SHELTER EXIT/ENTRY SEQUENCES: No exit procedure was used in this  
trial, as ensembles were put on outside of the shelter. Subjects  
entered the Shelter in numerical order at 5-minute intervals. The  
LHA impinger samplers ran on 5-minute cycles, and each subject's  
entrance was at the 2-minute mark of the samplers cycle.

**SIMULANT VAPOR CHALLENGE:** To simulate the vapor build-up in the shelter by previously contaminated personnel, an MeS vapor challenge was generated in the LHA using four 50-ml heated pots. The pots were heated using a flask heating mantle (MIC P-50). The pot locations were:

- a. outside wall of LHA (VHA archway side) between 3rd and 4th column of hangers (from VHA wall), first row of hangers;
- b. outside wall of LHA, between 3rd and 4th column on floor;
- c. inside wall of LHA, between 4th and 5th hanger (from VHA wall), first row of hangers;
- d. inside wall of LHA, between 5th and 6th hanger, on floor.

Pots were heated for a least 30 minutes prior to the entrance of the first subject to ensure that steady state concentrations had been reached.

A power supply was used to control the rate of evaporation from the pots. The voltage drop across the pots for each day of the trial were:

<u>Day</u>	<u>Voltage Drop (VAC)</u>
1	57
2	44
3	54
4	65

**LOCATION OF SIMULANT VAPOR SAMPLERS:**

LHA overboot Don/Doff Area (Sample Site (SS) 1)

LHA changing chute one, two, and three (SS 4, 3, and 2)

LHA Mask Storage Area (SS 5)

VHA Bench Area (SS 7)

TFA Offgassing Booth One, Two, Three, and Four (SS 11, 12, 13, and 14)

Tenax tubes were also used to monitor MeS vapor concentration on all trial days except Day 3. The following table lists tube location and exposure times for the 12 tubes used during a trial day. Two tubes were placed at each site.

<u>Location</u>	<u>Exposure Time (min)</u>	<u>Position</u>
A. On LHA Attend.*	20	Between fatigues and underwear
B. SS 2	15	Next to last tube in rack
C. On Subj. No. 2	5	Chest, between underwear and fatigues
D. On Subj. No. 2	3	Chest, between fatigues and CDE jacket
E. On Subj. No. 4	5	Chest, between underwear and fatigues
F. On Subj. No. 4	3	Chest, between fatigues and CDE jacket

\*LHA attendant did not wear ensemble jacket or trousers.

DON-DOFF PROCEDURES: No don procedure was used; subjects put on their ensemble outside the shelter. Standard doffing procedures were used in the LHA during shelter entry. Each subject remained at the overboot exchange area for 3 min, and at the changing chute for 5 min. Subjects did not remove any clothing during the first two min in the changing chute (0:00-2:00). The CDE jacket was removed during the third minute (2:00-3:00). The Tenax tubes at locations D and F were removed and capped just before the jacket was removed. The CDE trousers were removed during the fourth minute (3:00-4:00). The subject stood in the chute with no charcoal garments on during the last minute (4:00-5:00). An assistant helped the subjects remove the overgarments in the changing chute. Changing Chute 2 was used everyday except on Day 4, when Chute 3 was used.

After five minutes in the changing chute, the subject walked to the VHA archway, exchanged the mask, and stepped into the VHA. Tenax tubes at locations C and E were removed and capped immediately after the subject entered the VHA. As quickly as possible, the subject then removed leather boots and fatigues, and proceeded to the TFA airlock. After two minutes, the subject left the airlock and immediately entered the pre-assigned offgassing booth.

#### SUMMARY OF TEST RESULTS

Table 1 gives the Daily Mean/Challenge Concentration over the 20 min period that subjects were in the changing chute.

TABLE 1. DAILY MEAN/CHALLENGE CONCENTRATION  
 IN LHA CHANGING CHUTE

Day	Conc. (mg/m <sup>3</sup> )
1	20.8
2	7.2
3	8.4
4	32.5

Table 2 lists the skin Ct for each subject in the changing chute. The subject's Ct was calculated by multiplying the concentration for their 5 min residence period by 3 mins.

TABLE 2. SUBJECT SKIN Cts (mg min/m<sup>3</sup>) IN CHANGING CHUTE

Day	Subject No.			
	1	2	3	4
1	55.6	63.6	61.8	68.8
2	17.2	17.1	30.0	21.7
3	21.3	24.2	27.1	28.6
4	82.2	92.4	103.0	109.7

Table 3 gives the concentration measured with the Tenax tubes at each location. The concentrations are the mean of the two measurements made at each site.

TABLE 3. CONCENTRATIONS (mg/m<sup>3</sup>) MEASURED WITH TENAX TUBES

Position	Day		
	1	2	4
A	9.1	3.3	15.5
B	33.6	12.0	44.5
C	2.1	1.3	4.9
D	22.7	4.7	24.7
E	2.1	1.5	7.5
F	24.0	6.7	13.3



Table 4 lists the maximum offgassing booth vapor concentration (MBC) corrected for background, for each subject.

TABLE 4. OFFGASSING BOOTH MAXIMUM CONCENTRATION (mg/m<sup>3</sup>)

Day	Subject			
	1	2	3	4
1	.057	.084	.081	.096
2	.024	.025	.028	.022
3	.018	.031	.020	.016
4	.072	.142	*	.129

\*Subject opened door.

OBSERVATIONS AND CONCLUSIONS: Figure 1 plots the subject's changing chute Ct against their MBC for each day. The MBC in the offgassing booth was linearly related to the subject Ct in the changing booth. If t was set at 3 mins (the time the subject was in fatigues only), the relationship for all of the subjects

$$MBC = -.0068 + .0013 Ct$$

where vapor concentrations are expressed in milligrams per cubic meter (mg/m<sup>3</sup>).

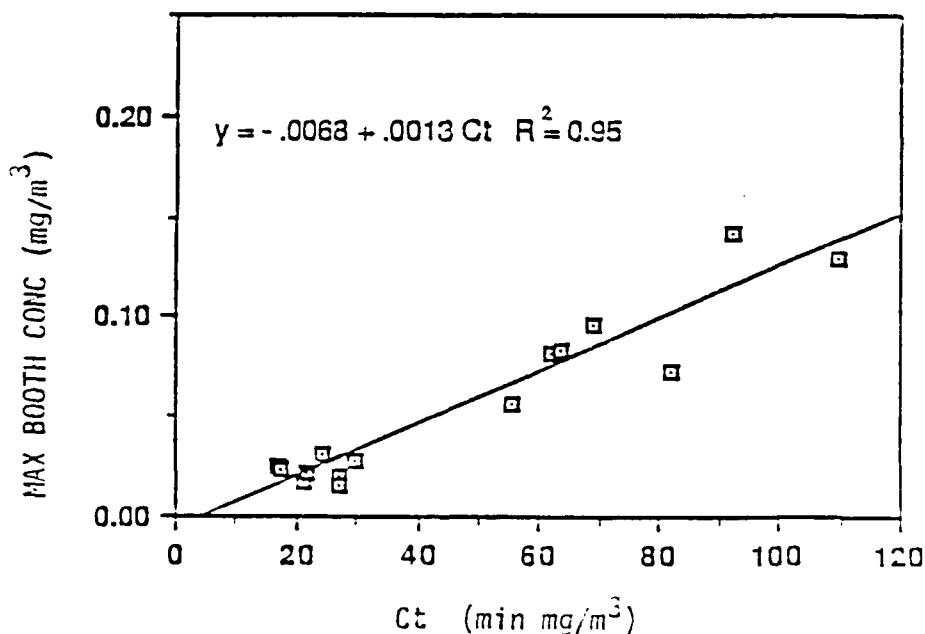


Figure 1. Skin Ct vs. Maximum Booth Concentration for all subjects.

When the data is plotted for each subject separately, as in Figure 2, the relationship between skin Ct (or the exposure Ct while subjects had no charcoal garment on), the relationship between the Cts and MBCs becomes more linear.

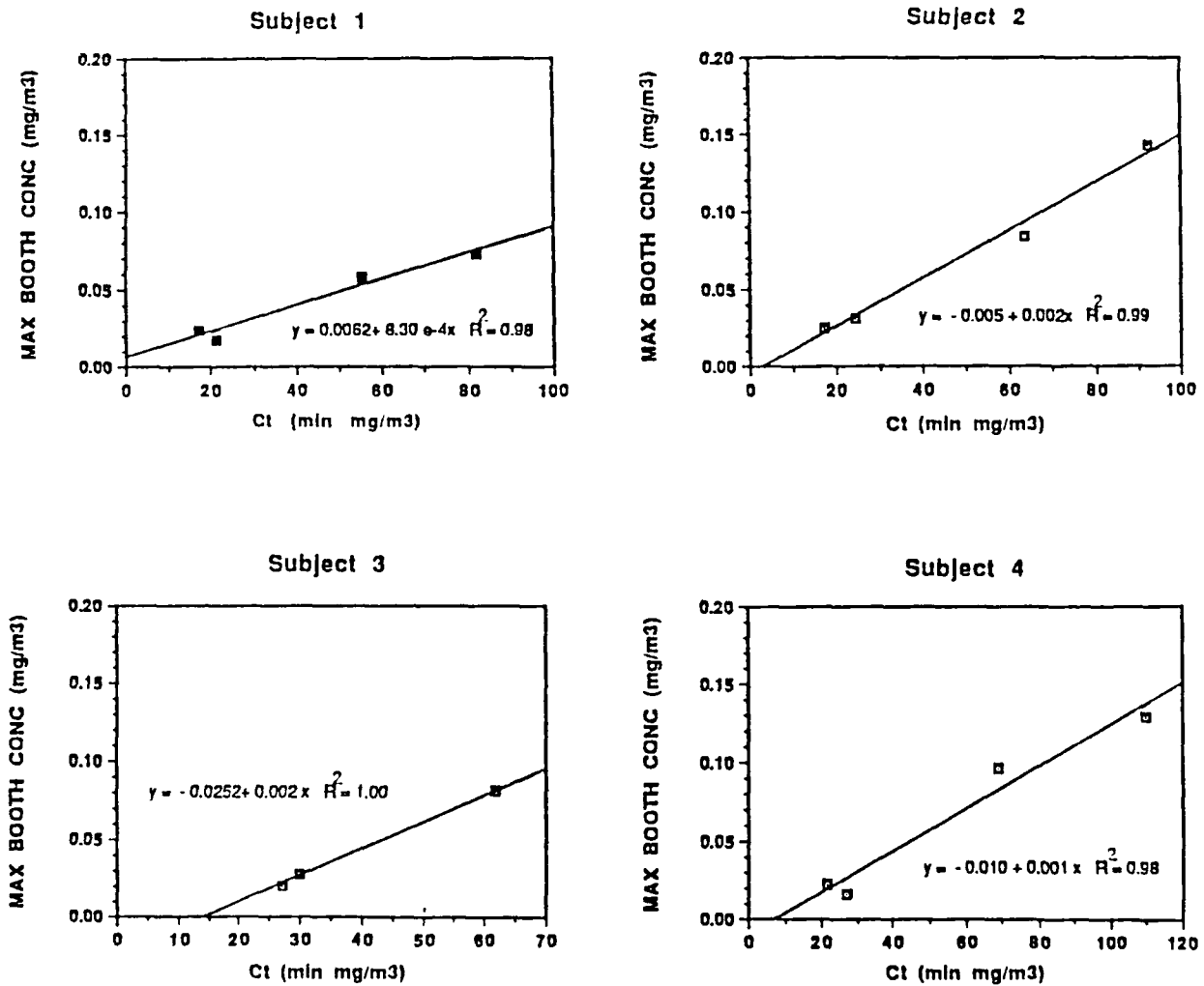


Figure 2. Skin Ct vs. Maximum Booth Concentration for each subject.

Table 5 lists the protection factors for the different layers of the ensemble, as measured with the Tenax tubes. The protection factor is calculated by dividing the external concentration, measured at location B, by the concentration at the other locations. The fatigues offered a protection factor of 3.4 on the LHA attendant, 11.4 on Subject No. 2, and 10.0 on Subject No. 4. The low protection factor provided by the attendant's fatigues may have been due to a greater level of activity (more convection through the fatigue material), lack of ensemble jacket, or a greater exposure time, which may have saturated the fibers in the fabric.

TABLE 5. PROTECTION FACTORS MEASURED WITH TENAX TUBES

Location	Day			Location Mean $\pm$ S.D.
	1	2	4	
A	3.7	3.6	2.9	3.4 $\pm$ 0.4
C	16.0	9.2	9.1	11.4 $\pm$ 4.0
D	1.5	2.6	1.8	2.0 $\pm$ 0.6
E	16.0	8.0	5.9	10.0 $\pm$ 5.3
F	1.4	1.8	3.3	2.2 $\pm$ 1.0

Note: See page 3 for explanation.

The CDE jackets offered a protection factor of 2, a surprisingly low level of protection. There is no obvious explanation for this low value, the tubes may have been contaminated as they were capped. The jacket protection factor needs to be measured in a future study.

William R. Scott, Ph.D.  
Research Engineer

/vb.

(This is an amended version of the original summary  
that was sent out 4 December 1987.)

APPENDIX VI-H:  
VAPOR TRANSFER STUDY-ALTERNATE  
PROCESSING OF SPRAYED-UNSPRAYED SUBJECTS

# KRUG INTERNATIONAL

15 February 1988

Technology Services Division  
P.O. Box 790644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Dr. L. Luskus)  
Brooks AFB, TX 78235-5301

SUBJECT: Outline Procedures and Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 11-87-16 Conducted  
30 November 1987 - 3 December 1987

STUDY TITLE: Vapor Transfer Study-Alternate Processing of  
Sprayed-Unsprayed Subjects.

FACILITY USED: USAFSAM/VNC SCPS-2B

FACILITY AIRFLOW: 1800 cfm

AIRLOCK AIRFLOW: 600 cfm

SUBJECT AIRLOCK DWELL TIME: 2 min

NO. OF TEST SUBJECTS USED: 4

NO. OF TEST DAYS: 4

TFA OFFGASSING BOOTHS USED: Four booths used on each test day  
with each subject using each of the booths over the four test  
days. Subjects offgassed in the booths for 2 h on each test day.

BLACK LIGHT (UV) SCANNING: The four test subjects were UV scanned  
pretest and after exit from the offgassing booths.

SHELTER EXIT/ENTRY SEQUENCES: All subjects completed one exit-  
spray challenge-entry sequence on each day. The entry sequence  
was:

<u>Position</u>	<u>Subject Status</u>
1st	Sprayed
2nd	Unsprayed
3rd	Sprayed
4th	Unsprayed

---

DON-DOFF PROCEDURES: Basically standard procedures, but with attendant assistance for doffing contaminated outer garments and gloves, and for mask exchanges. Changing Chute #3 (below Sampler Site (SS) 2) was used by all subjects during the exit and entry procedures. Contaminated outer garments were stored on the inside wall of the CCA, below SS 5.

SIMULANT SPRAY CHALLENGE: Neat methyl salicylate with Tinopal additive. Target dosage of 5 g m per subject.

SUBJECTS' TEST ENSEMBLE:

New ground crew chemical protective overgarments

Fatigue Jacket and Trousers

\*Socks-Tube-Men's, White

\*T-Shirt-White

\*Jockey Shorts-White

Gloves-Set, CP, Groundcrew

Gloves, Insert-White

Boots-Flyers', FWU. 3/P

Overboot-CP

Mask CB Prot M17 + Hood

Plastic Bag Overboots

\*These items worn by subjects on entry to TFA/offgassing booths.

LOCATION OF SIMULANT VAPOR SAMPLERS AND SAMPLER SITE NUMBER (SS NO.):

LHA Overboot Don/Doff Area (SS No. 1)

LHA Changing Chute Nos. 1, 2, and 3 (SS Nos. 4, 3, and 2, respectively)

LHA Mask Storage Area (SS No. 5)

VHA Mask Exchange Archway (SS No. 6)

VHA No. 1 Airlock Area (SS No. 7)

TFA Scanning Booth Area (SS No. 10)

TFA In Each Offgassing Booth No. 1 (SS No. 11), Booth No. 2 (SS No. 12),  
Booth No. 3 (SS No. 13), and Booth No. 4 (SS No. 14)

DECONTAMINATION: Sprayed test subjects dusted themselves with fuller's earth after entering the SCPS-2B Facility. Excess fuller's earth was removed by brushing. Unsprayed subjects did not dust themselves with fuller's earth. All subjects cleaned gloved hands in the CCA in accordance with the entry procedures.

SUMMARY OF TEST RESULTS

LIQUID SIMULANT CHALLENGE TO TEST SUBJECT (g/m<sup>2</sup>)

Subject	Day			
	1	2	3	4
1	1.644	3.412	*	*
2	*	*	5.348	5.417
3	2.770	3.588	*	*
4	*	*	4.073	1.046
	2.207	3.500	4.709	3.232

\*Subject not sprayed on this day.

MAXIMUM VAPOR CONCENTRATIONS (mg/m<sup>3</sup>) IN THE SHELTER  
(CORRECTED FOR RESIDUAL BACKGROUND)

Sampler Site	Day			
	1	2	3	4
LHA-Overboot Change Area	2.126	3.484	2.254	1.617
LHA-Chute No. 3	1.550	1.474	1.288	.491
LHA-Mask Storage Area	.266	.324	.209	.179
VHA-Mask Exchange Area	.003	.007	.005	.005
VHA-Airlock Area	.002	.002	.002	.003
TFA-Scanning Booth Area	.001	.000	.001	.000

OFFGASSING BOOTH MAXIMUM VAPOR CONCENTRATION (mg/m<sup>3</sup>)  
(CORRECTED FOR RESIDUAL BACKGROUND)

Subject	Day			
	1	2	3	4
1	.021*	.038*	.005	.005
2	.002	.002	.108*	.037*
3	.026*	.023*	.007	.012
4	.002	.003	.023*	.008*
Mean	.013	.017	.036	.014

\*Sprayed subjects

Mean maximum booth concentration for unsprayed  
subjects =  $.005 \pm .003$  mg/m<sup>3</sup>

Mean maximum booth concentration for sprayed  
subjects =  $.036 \pm .031$  mg/m<sup>3</sup>

BLACKLIGHT (UV) SCANNING OF TEST SUBJECTS: The UV scanning of the test subjects, post-test, indicated that no subjects sustained any liquid transfer.

OBSERVATIONS AND CONCLUSIONS: The mean simulant dosage applied to the test subjects was  $3.816 \text{ g m}^{-2}$ ; the target dose was  $5 \text{ g m}^{-2}$ . Daily dosage varied greatly, because three different people performed the spraying.



USAFSAM/VNC (Dr. Luskus)  
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The mean maximum offgassing booth vapor concentrations for unsprayed subjects were 13.4% of the values of the sprayed subjects.

William R. Scott, Ph.D.  
Research Engineer

/vbj

APPENDIX VI-I:  
SIMULANT VAPOR CONCENTRATIONS UNDER  
THE GROUND CREW CHEMICAL DEFENSE ENSEMBLE (CDE)

# KRUG INTERNATIONAL

30 June 1988

Technology Services Division  
P.O. Box 799644  
San Antonio, Texas 78279-0644  
512-349-3925

USAFSAM/VNC (Dr. Luskus)  
Brooks AFB, TX 78235-5301

SUBJECT: Outline Procedures and Test Results of USAFSAM/VNC  
Chemical Defense Facility Study No. 03-88-19 Conducted  
30-31 March 88; 12 Apr 88; 3-5 May 88; 9-10 May 88

STUDY TITLE: Simulant Vapor Concentrations Under the Ground  
Crew Chemical Defense Ensemble (CDE).

FACILITY USED: USAFSAM/VNC SCPS-3 LHA

NO. OF TEST SUBJECTS: 2

PROCEDURE: Two test subjects wearing the ground crew CDE with  
two different configurations--standard and with hood skirt  
tucked in (zipper taped over)--entered the SCPS-3 LHA which  
contained a simulant vapor challenge (methyl salicylate) of  
approximately 25 mg/m<sup>3</sup>. The vapor was generated by evaporating  
400 µl of methyl salicylate in two heated pots.

In the vapor challenge area, the subjects performed the follow-  
ing set of exercises every 5 minutes:

<u>Time</u>	<u>Exercise</u>
0-1 min	walk in place
1-2 min	extend arms straight up
2-3 min	touch toes
4-5 min	stand still

Subjects remained in the vapor challenge for 20 minutes and  
performed four cycles of the exercise regimen.

Vapor concentrations in the vapor challenge area CDE were measured with Tenax tubes and impinger tubes. Vapor concentrations under the CDE were measured with Tenax tubes. Tubes were uncapped just before the subjects entered the vapor challenge area and were capped in the open air outside of Bldg 1192 immediately after the subjects left the vapor challenge area.

The following table lists the locations at which vapor concentrations were measured under the CDE, the mean concentration at that site (as a % of the outside concentration), the standard deviation, and n (the total number of measurements at each site; combined samples).

<u>Location</u>	<u>% Of Outside Concentration</u>
Chest (on fatigue chest pockets)	4.82% ± 2.10% (n = 15)
Hips (fatigue pant pockets)	1.25% ± .5% (n = 8)
Neck Area (on fatigue collar)	
Standard Configuration (skirt out)	28.10% ± 13.78% (n = 12)
Hood Skirt Tucked In	2.41% ± .83% (n = 12)
Stomach (near solar plexus)	17.51% ± 12.12% (n = 15)
Lower Back (above waist)	2.90% ± 2.17% (n = 16)
Forearm	3.57% ± 2.79% (n = 12)
Calf	2.73% ± 1.55% (n = 8)

OBSERVATIONS AND CONCLUSIONS: In the standard CDE configuration, there was extensive vapor penetration below the butyl hood and in the stomach area. The skin Ct in the neck area averaged  $140 \text{ mg min m}^{-3}$ . Tucking the skirt of the hood under the CDE jacket reduced the vapor levels at the neck by 91.4%.

Vapor penetration in the stomach area appears to be due to gaps between the jacket and trouser overlap. The excess volume of material in the jacket in the stomach area makes the jacket act as a bellows type pump when the subject stretches upward or bends at the waist. Improved sizing and a better design of the waist/jacket intersection may be needed to reduce the vapor penetration in this area.

William R. Scott, Ph.D.  
Research Engineer

/db

PART VII:

CENTRIFUGE SUPPORT

Robert W. Krutz, Jr.

A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Statement of Work required technical support in the performance of scheduled and unscheduled maintenance on the USAFSAM human-use centrifuge and associated systems and in the performance of centrifuge modifications as approved by the technical contract monitor.

B. ACCOMPLISHMENTS

B.1 Centrifuge Modifications

An electronic filter circuit was designed and installed to increase stability in the drive regulator and thus eliminate distracting "rumbling" noise. Engineering drawings and documentation are available in the Systems Engineering Branch of the Crew Technology Division.

A "check six" LED display was designed and fabricated for use in the Tactical Air Command high-G training program. Engineering drawings and documentation are available in the Systems Engineering Branch of the Crew Technology Division.

A modification using an operational amplifier was installed to prevent a delay occurring between the time tachometer feedback was lost and the time the centrifuge drive was shutdown. This modification eliminated a potential safety hazard.

A device to "soften" the start of the centrifuge was designed, fabricated, and installed. The design does not compromise the safety of centrifuge operations.

All scheduled maintenance was performed in accordance with Technical Order (TO) 43D8-7-2-6WC-1.

PART VIII:

CENTRIFUGE TESTING OF LIFE SUPPORT EQUIPMENT

Robert W. Krutz, Jr.

A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Statement of Work (SOW) required the collection of engineering test data from unmanned centrifuge testing of life support equipment (LSE). Although provisions were made for unmanned testing of other LSE items, only anti-G valve testing was required.

B. ACCOMPLISHMENTS

B.1 Unmanned Testing and Evaluation of Anti-G Valves

The necessity to improve G-protection has prompted research yielding the definition of optimal inflation schedules and many new concepts in anti-G valve design. Among the products of this research are four candidate anti-G valves. Unmanned testing and evaluation of these four valves involved the use of low stretch bladders to simulate G-suit volumes. A variety of valve angles, source pressures, G-onset rates and G-suit volumes were used.

Published works relating to unmanned anti-G valve testing are listed in Appendix VIII-A.

APPENDIX VIII-A:

PUBLICATIONS DOCUMENTING CENTRIFUGE TESTING OF LIFE SUPPORT EQUIPMENT

Meeker LJ, Krueger AG, Love PE. An engineering test and evaluation of the French EROS, MOOG/Carleton and Garrett Fluidic anti-G valves. Proceedings of the 25th Annual SAFE Symposium, pp. 54-57, Las Vegas, NV, 1988.

Meeker LJ, Krueger AG. Test and evaluation of the Hymatic Rodditch anti-G valve. Proceedings of the 26th Annual SAFE Symposium, pp. 32-35, Las Vegas, NV, 1989.

PART IX:

COCKPIT INTEGRATION

Thomas E. Nesthus

A. SUMMARY OF OBJECTIVES AND DESCRIPTION OF WORK

The Statement of Work required the evaluation of equipment in support of the Cockpit and Equipment Integration Laboratory (CEIL) mission which is to: (1) enhance operator/aerospace system integration; (2) optimize human performance through improved life support systems; and (3) support USAFSAM laboratories in personal protective equipment (PPE) research development test and evaluation (RDT&E).

B. ACCOMPLISHMENTS

B.1 Procedures

Prototype PPE and life support systems were evaluated based on effectiveness of cockpit integration with existing production equipment. The CEIL followed similar procedures from one evaluation to another. The procedures identified potential problems with the new equipment that could affect a crewmember's job performance in the cockpit. For hardware other than PPE, cockpit-location requirements were assessed. Feasibility tests were run on panel rearrangement, hose and wire routing/securement, and other changes to determine the effects of changing the standard cockpit configuration to accommodate the new equipment.

Although each item of PPE or life support system involved an integration study tailored to specific equipment requirements, the procedures followed a basic outline, including: (1) A subject panel representing appropriate anthropometric percentile-ranges of the USAF crewmember population was selected. All subjects were measured and classified according to population statistics. The anthropometric measurements were stored in the laboratory's computer database for later reference. (2) Subjects donned the equipment along with all standard USAF PPE specified. Fit, comfort, and ease of donning and doffing were surveyed. (3) Subjects then performed cockpit-mockup ingress and normal strap-in procedures. Then an aircraft preflight checklist procedure was conducted, accessing all controls. Routine and simulated combat cockpit activity was performed to assess man-equipment movement interaction. (4) Internal and external cockpit field-of-view capability was determined by drawing 2-dimensional plots on specialized forms for specific tactical fighter mock-ups. (5) Any potential subject/cockpit interference, subject performance decrement, and integration failure was duly noted with modification suggestions appended. (6) Normal and emergency air and ground egress procedures were followed to determine equipment impact and integration problems. (7) Subjects were strapped into an ejection seat-inversion wheel to assess PPE displacement under  $\pm 1 G_x$  and  $G_y$ , and  $-1 G_z$ . (8) Subjects wearing appropriate torso/parachute harness<sup>x</sup> were suspended from a parachute riser suspension rig, simulating parachute descent. Any interference with performance of these procedures was noted. (9) Water landing procedures were followed



as subjects were lowered or dropped into a water tank (Bldg 820). After-water-landing procedures, such as doffing appropriate PPE and climbing into a life raft were then checked. Since each item of PPE warranted tailored integration evaluations, some of the preceding procedures were modified or omitted. Where possible, experimental design procedures were tested--such as counterbalancing the order of comparison between production USAF ensembles and prototype PPE or life support systems. Much of the data collected, however, were subjective, and conclusions were so tempered. Many of the PPE and life support system items would eventually be flight-tested and hence require "man-rating" for a safe-to-fly clearance. The CEIL personnel supported this process by maintaining the equipment, by assisting with proper don/doff procedures, by troubleshooting and assisting with minor equipment modification or design-change suggestions, by assisting with altitude and centrifuge testing through making fine adjustments to improve equipment performance, and by performing other duties necessary for program support.

## B.2 Equipment Evaluated

The major items of PPE and life support system equipment evaluated during this contract period included:

- 1) Tactical Life Support System (TLSS)
  - a) Standard ensemble
  - b) A-respirator, vapor threat CD ensemble
  - c) B-respirator, liquid threat CD ensemble
- 2) Positive Pressure Breathing under G (PPB/G) program
  - a) TLSS vs French AF system in F-16
- 3) Aircrew Eye Respiratory Protection Program (AERP)
  - a) Tactical Aircrew Eye Respiratory System (TAERS)
  - b) Protective Integrated Hood/Mask (PIHM) System
- 4) Integrated Aircrew Chemical Defense Coverall (IACDC)
- 5) NASA/Lockheed partial pressure suit (Space Shuttle ascent/descent garment)
- 6) Modified TLSS program (for loads-testing procedures at Edwards AFB, CA)
- 7) Assisted Positive Pressure Breathing (APPB) Program also called Combat EDGE (Enhanced Design G-Ensemble)
- 8) Uniform Pressure Suit (G-training for Edwards AFB Student Test Pilot Project)

B.3 Results

The results of the tests and evaluations performed during this contract were written into CEIL letter reports by the military personnel assigned to USAFSAM/VNL-CEIL. The data and reports can be accessed by contacting the OIC of the Cockpit and Equipment Laboratory, USAFSAM/VNL.

PART X:

OXYGEN SYSTEMS

Cherie J. Noles

A. SUMMARY OF OBJECTIVE AND DESCRIPTION OF WORK

The Statement of Work required support in the research and development of On Board Oxygen Generation Systems (OBOGS) and On Board Inert Gas Generation Systems (OBIGGS). The SOW specified the use of a Mass Spectrometer to analyze air samples.

B. ACCOMPLISHMENTS

B.1 General

Technical support was provided for research and development of On Board Oxygen Generation Systems (OBOGS) and On Board Inert Gas Generation Systems (OBIGGS). The efforts included construction and modification of lab tabletop units that utilize the principle of pressure swing adsorption (PSA); OBOGS and OBIGGS employ PSA technology. Assistance was also provided with data collection, data analysis, and preparation of publications listed in Appendix X-A. Several computer programs were written to enhance the research. All programs were written in GW BASIC or FORTRAN and stored on 5-1/4 in floppy disks located in the Crew Systems Branch laboratory and on the SAM780 VAX, respectively.

B.2 Molecular Sieve for On Board Storage of Gaseous Oxygen and Nitrogen

Molecular sieve technology, related to pressure swing adsorption, the fundamental principle of the OBOGS, has advanced considerably in the past decade. Molecular sieve is used not only for air separation, but also for pressurized storage of gaseous oxygen and nitrogen. This storage capability became attractive when it was demonstrated that it was possible to store three times as much oxygen and four times as much nitrogen in a plenum filled with molecular sieve than in an empty plenum of the same size pressurized at the same pressure. Molecular sieve types 5A, MG-3, and 4A were tested to determine their storage capacities (Ikels et al., 1987; Appendix X-A).

B.3 Attrition of Molecular Sieve in On Board Oxygen Generating Systems

Under actual operating conditions, in the B-1B On Board Oxygen Generation System, there has been evidence of attrition (so-called "dusting") of molecular sieve beds. In other aircraft, i.e., AV-8 "Harrier," operational OBOGS have had no attrition problems, however, two cases of dusting in the B-1B aircraft, reported in 1987, warranted an investigation. The Crew Systems Branch of the Crew Technology Division identified the probable causes of dust generated from the breakdown of the molecular sieve. Since the conclusion of this research, there have been additional cases of dusting reported in the B-1B. It is believed that all of these failures were caused by sieve exposure to liquid water and the bed retention design (Noles, et al., 1988; Appendix X-A).

#### B.4 A Small Inert Gas Generator

Although oxygen generation is the primary area of interest, it was agreed that the Crew Systems Branch laboratory would dedicate resources and research effort into nitrogen generation as well for fuel tank inerting. While OBOGS produces an oxygen-enriched product gas for use by aircrew at high altitude, the OBIGGS produces an oxygen-depleted product gas used in aircraft fuel tanks to cover the fuel; the inert gas generated by OBIGGS fills the space vacated by burned fuel to lower combustibility in the event that ordnance penetrates the fuel tank, or during a crash landing. A small inert gas generator (SIGG), modeled after the small oxygen concentrator (SOC), was built capable of delivering an inert product gas of 99.9%. The construction of the system and its performance data were presented at the 1988 SAFE Symposium (Scheie et al., 1989; Appendix X-A). The raw data and software programs are available on floppy disks. The data collection program was written in GW BASIC; all data are stored in LOTUS 1-2-3 spreadsheets located in the Crew Systems Branch.

Data were collected in tests conducted using bed lengths of 16 and 36 inches with no microbore tubing; exhaust pressure was 380 mmHg. These tests were similar to tests previously conducted which used a bed length of 24 inches. Under these conditions, the 36-inch beds produced the higher inert gas concentration. The lower inert gas concentration was achieved using the 16-inch bed. All data are stored in the Crew Systems Branch.

#### B.5 OBOGS Research/Literature Data Base

The OBOGS and OBIGGS library was created to consolidate published information on OBOGS, OBIGGS, pressure swing adsorption technology, and other subjects associated with Oxygen System research. The database was developed on a Zenith PC using the software DBASE II. The database name is OBOGS; it can be found on a 5-1/4 inch floppy disk or on the hard drive of the Zenith PC located in the Crew Systems Branch laboratory. The database structure contains 13 fields for data entry or retrieval. The procedure for operating this database can be found in the Zenith DBASE II operation manual. A hard copy of each article entered in the database can be located in the letter boxes in the Crew Systems Branch laboratory. The articles are filed by the primary authors' last name. A detailed description of retrieval and print procedures are located in the front of these letter boxes. Currently, all articles in the database are alphabetized according to authors and year of publication.

APPENDIX X-A:

PUBLICATIONS DOCUMENTING OXYGEN SYSTEMS RESEARCH

Ikels KG, Noles CJ. Molecular sieve for on board storage of gaseous oxygen and nitrogen. Proceedings of the 24th Annual SAFE Symposium, pp. 283-287, San Antonio, TX, 1987.

Noles CJ, Ikels KG. Attrition of molecular sieve in on board oxygen generating systems. Proceedings of the 25th Annual SAFE Symposium, pp. 12-15, Las Vegas, NV, 1988.

Scheie PO, Ikels KG, Noles CJ. A small inert gas generator. Proceedings of the 26th Annual SAFE Symposium, pp. 27-31, Las Vegas, NV, 1989.

## PART XI:

### HUMAN FACTORS SUPPORT

Thomas E. Nesthus

#### A. SUMMARY OF OBJECTIVES AND DESCRIPTION OF WORK

The requirement for human factors support included the conduct of human performance research under simulated flight conditions for the Crew Performance Laboratory. The technical and scientific staffmember was expected to conduct research according to approved protocols. Human performance data would be collected and analyzed to determine potential performance impact related to prototype PPE, and to other life support equipment under simulated flight conditions in a hypobaric (altitude) chamber environment.

#### B. ACCOMPLISHMENTS

##### B.1 Review of Human Performance Research

An experiment was designed to determine performance impairment under simulated worst-case profiles in a hypobaric chamber. In the study, the effects of breathing molecular sieve product breathing gas (93% oxygen) were investigated before and after a rapid decompression from a simulated altitude of 20,000 to 50,000 ft in a hypobaric chamber. Comparisons were made with other breathing gas mixtures including 99.5% oxygen or Aviator's Breathing Oxygen (ABO), 90% oxygen and 85% oxygen with the breathing regulator set on the normal dilution mode and on the 100% emergency mode under the same altitude profile conditions. Appendix XI-A lists all published works relating to this research project. The raw data from this research project are located on the SAM780 VAX computer system controlled in the Statistics Function of the Systems Engineering Branch.

##### B.2 Additional Human Factors Support

Another area of research involved assistance with alpha level (1st phase) debug/development of a cognitive and psychomotor performance task battery authoring software system called the Unified Tri-Services Cognitive Performance Assessment Battery (UTC-PAB). The software system is a two part configuration and runtime system. Human/computer software interface issues as well as software "bug" identification test procedures were followed. A research protocol, "An Assessment of the Sensitivity of Selected Cognitive Performance Tasks to Antihistamines Under Normal and Sustained Operation Conditions" (Protocol No. ACHE # 88-22), was written; it was approved by the Advisory Committee for Human Experimentation (ACHE) and the USAFSAM Commander. The UTC-PAB software system was used to develop and run a performance task battery for assessing the effects of antihistamines under normal and sustained operations conditions.

APPENDIX XI-A:

PUBLICATIONS/ABSTRACTS/PRESENTATIONS DOCUMENTING  
HUMAN FACTORS/HUMAN PERFORMANCE RESEARCH

- Bomar JB Jr, Holden RD, O'Connor RB, Wright CS, Nesthus TE. Effect of OBOGS breathing gas concentrations on crew performance at high altitude. (Abstract) Aviat Space Environ Med 59:471(52) (1988).
- Holden RD, Bomar JB Jr, O'Connor RB, Wright CS, and Nesthus TE. Acceptability of standard USAF breathing gear at high altitude. Proceedings of the 25th Annual SAFE Symposium, pp. 166-170, Las Vegas, NV. 1988.
- Nesthus TE, Schiflett SG, Bomar JB. The effects of various breathing gas mixtures on cognitive and psychomotor task performance at high altitude. Abstract submitted for Human Factors Society 33rd Annual Meeting, 16-20 October 1989, Denver, CO.
- Nesthus TE, Bomar JB Jr, Holden RD. Hypoxia symptoms resulting from various breathing gas mixtures at high altitude. Proceedings of the 26th Annual SAFE Symposium, pp. 16-21, Las Vegas, NV, 1989.
- Nesthus TE, Schiflett SG, Bomar JB Jr, Holden RD. The effects of different breathing gas concentrations on task performance at high altitude. (Abstract) Aviat Space Environ Med 59:472(53) (1988).
- Nesthus TE, Bomar JB Jr, Holden RD, O'Connor RB. Cognitive workload and symptoms of hypoxia. Proceedings of the 25th Annual SAFE Symposium, pp. 45-47, Las Vegas, NV, 1988.
- Nesthus TE. An assessment of cognitive workload and hypoxia symptoms. Minutes of the Oxygen Standardization Coordinating Group Meeting No. 50, San Antonio, TX, 1988.
- Wright CS, O'Connor RB, Holden RD, Nesthus TE, Bomar JB Jr. Heart rate response after rapid decompression to 50,000 feet: The effect of 93% oxygen breathing gas. (Abstract) Aviat Space Environ Med 59:472(54) (1988).