



EDGEWOOD

CHEMICAL BIOLOGICAL CENTER

U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

ECBC-TR-421

**DOMESTIC PREPAREDNESS PROGRAM:
SARIN (GB) AND MUSTARD (HD) CHALLENGE AND
PROTECTION FACTOR (PF) TESTING OF ESCAPE HOODS,
DRAEGER DEFENDAIR AND FUME FREE QUICK MASK 2000**

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November 2004

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) XX-11-2004		2. REPORT TYPE Final		3. DATES COVERED (From - To) Jul 2002 - Oct 2002	
4. TITLE AND SUBTITLE Domestic Preparedness Program: Sarin (GB) and Mustard (HD) Challenge and Protection Factor (PF) Testing of Escape Hoods, Draeger DefendAir and Fume Free Quick Mask 2000				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Campbell, Lee E.; and Seiple, Adam D.				5d. PROJECT NUMBER None	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES) DIR, ECBC, ATTN: AMSRD-ECB-RT-AE/AMSRD-ECB-ENE-M, APG, MD 21010-5424				8. PERFORMING ORGANIZATION REPORT NUMBER ECBC-TR-421	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) DIR, ECBC, ATTN: AMSRD-ECB-ENH, APG, MD 21010-5424				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Two escape hood designs (Draeger DefendAir and the Fume Free Quick Mask 2000) were tested to assess their capability to protect in a chemical warfare (CW) agent environment. Sarin and mustard vapor tests were performed on both types of hoods, and there were no breakthroughs during the 65-min tests. The hoods were also tested to assess their ability to protect the wearer from an aerosolized threat. Human test subjects donned the hoods and entered a corn oil aerosol chamber. The Draeger DefendAir achieved a 95.8% pass rate at a PF of 2,000, and the Fume Free Quick Mask 2000 achieved a 100% pass rate at a PF of 2,000.					
15. SUBJECT TERMS GB Sarin Mustard HD Corn oil Aerosol Respirator Cartridge/Canister Sarin-Challenge Testing Protection Factor (PF) Testing					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Sandra J. Johnson
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EXECUTIVE SUMMARY

As part of the Domestic Preparedness Program, two escape hood designs were tested to assess their capability to protect in a chemical warfare (CW) agent environment. The two designs were the Draeger DefendAir and the Fume Free Quick Mask 2000. Sarin (GB) and mustard (HD) vapor tests were performed on both types of hoods, and there were no breakthroughs during the 65-min tests.

The hoods were also tested to assess their ability to protect the wearer from an aerosolized threat. Human test subjects donned the hoods and entered a corn oil aerosol chamber. The subjects then performed a series of exercises to stress the seals of the hoods. A continuous sample was pulled from the oronasal region and analyzed by a laser photometer to see if any corn oil aerosol had entered the hood. The Draeger DefendAir achieved a 95.8% pass rate at a PF of 2,000, and the Fume Free Quick Mask 2000 achieved a 100% pass rate at a PF of 2,000.

PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Edgewood Chemical Biological Center (ECBC) Homeland Defense Business Unit. The work was started in July 2002 and completed in October 2002.

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DOMESTIC PREPAREDNESS PROGRAM:
SARIN (GB) AND MUSTARD (HD) CHALLENGE AND
PROTECTION FACTOR (PF) TESTING OF ESCAPE HOODS,
DRAEGER DEFENDAIR AND FUME FREE QUICK MASK 2000

1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction, including nuclear, biological, and chemical (NBC) weapons. The DoD responded by establishing the Domestic Preparedness Program that same year. This program tasked the U.S Army Edgewood Chemical Biological Center (ECBC) to perform chemical agent resistance testing of various types of protective respirators that might be used in response to a terrorist event.

Personnel who are present at the scene of a terrorist incident that involves NBC, and who are not among the responder personnel, can be expected to leave the scene if circumstances permit. In such situations, an escape safety filter hood should be donned to enable personnel to breathe clean air until they arrive at a safe location remote from the original incident site. A number of safety devices are commercially available that protect against smoke, toxic fumes, aerosols, carbon monoxide, and other gases and vapors that would be harmful if breathed in. Almost none of these devices have been tested against chemical agents to assess the degree of resistance to the agents. Consequently, two escape hood designs were tested to determine their resistance to chemical agents. The escape hoods tested were the Draeger DefendAir and Fume Free Quick2000. The units were purchased on the open market.

2. OBJECTIVES

The objectives of this testing were to subject the escape hood to a high vapor challenge of GB (sarin, a nerve agent) and HD (mustard, a vesicant), and monitor the inside of the hood for presence of agent. Another objective was to determine a protection factor (PF), determined with human subjects and using the standard U.S. Army procedure. No U. S. Government regulatory agency has yet issued specifications for agent resistance of escape hoods, but NIOSH and DoD are actively pursuing such specifications. For the agent testing, the hood was mounted on a suitable test fixture operated by a breather pump. For this project, a minimum time of 15 min (30 min desirable) resistance to penetration by agents was used. These times have been used previously for testing escape masks. The total test time was set at 65 min.

3. CHEMICAL AGENT TESTING

Three escape hoods of each type were tested against each agent, GB and HD. For each test, the escape hood was mounted on a test fixture, called SMARTMAN (SiMulant Agent Resistant Test MANikin), which is a human head form and half-torso, with a movable face piece and an inflatable peripheral seal, that is installed in an exposure (test) chamber. The SMARTMAN is connected to a breather pump to simulate a person breathing inside the hood. Agent vapor was generated to a specified concentration in air, and the mixture was passed through the exposure chamber. The inside of the hood was monitored for presence of agent.

3.1 Chemical Test Equipment.

3.1.1 Vapor Generator.

GB and HD vapors were generated by using a syringe pump to inject liquid agent into a heated tee in the air dilution line. The rate of injection was such that the concentration of vapor was controlled to that specified in the test plan. The agent vaporized in the heated tee, was carried by the dilution air into the mixing chamber, thence into the exposure chamber. An Ambient Air Analyzer (MIRAN), Model 1A, was used to monitor the concentration in the test chamber during the test.

3.1.2 Exposure Chamber.

The test chamber is a Plexiglas box approximately 2 feet on each side, with a removable front panel and four legs on the bottom about 4 inches long, which allow air to flow under the chamber when it is located inside a fume hood. A SMARTMAN test fixture is attached to the floor of the chamber. The mouth orifice of the face piece is connected by a large tube to a breather pump; there are also two sampling tubes in the nose, one in the eye, and one in the forehead. All these tubes pass down through the interior of the head form, down through the floor of the chamber, and connect to remote detectors and the breather pump or other instruments, such as pressure gauges. Since agent-air mixture passes through the chamber during the test, the outlet ports on top of the chamber are covered by military M12A1 filters to scrub agent from the air passing through. Other ports in the chamber walls are used for introducing the agent challenge into the chamber, to attach pressure gauges, to introduce oil aerosol for preliminary leak testing of an installed respirator, or to monitor the agent concentration inside the chamber.

3.1.3 Breather Pump.

The military Breather Pump E1R1 (Jaeco Fluid Systems, Exton, PA) was used to simulate breathing through the hoods. This is a reciprocating pump that produces a sinusoidal breathing pattern by means of a gearing system that incorporates a Scotch Yoke. The pump produces a smooth peak flow approximately π times the min volume. The min volume (liters pumped in 1 min) and the number of strokes (breaths) per min can be adjusted.

3.1.4 Leak Detector, TDA-99M.

This leak detector is based on generating a polydispersed ($<1\ \mu\text{m}$ diameter) aerosol of Emery 3004 oil. The aerosol is introduced to the air surrounding the escape hood and air samples are drawn from outside and inside the hood. The samples are passed to the detector, where a light scattering chamber detects aerosol particles and compares the concentration outside the hood to the concentration inside the hood. The readout is expressed as percentage.

3.1.5 MINICAMS, Miniature Continuous Air Monitoring System.

The MINICAMS is a gas chromatograph equipped with a flame photometric detector and a preconcentrator tube. The preconcentrator tube is a small tube containing an adsorbent material to scrub out agent vapors contained in a sample of air drawn through it for a set period of time. The tube is then heated to desorb the agent and introduce it into the column and subsequently the detector. By preconcentrating the agent, the detection limit is lowered. The MINICAMS software calculates the amount of agent detected over the sampling period.

3.2 Chemical Agent Test Methods.

Since it would be prohibitively expensive to test a statistically significant number of escape hoods, only three hoods of each type were tested against each agent.

3.2.1 GB Vapor Procedure.

An escape hood was mounted on a SMARTMAN test fixture inside a clean exposure chamber, equipped with a breather pump. The pump was turned on, and the hood was checked for leakage, using aerosols generated by the TDA-99M Leak Tester. The leak test will give an indication of leak paths to the inside of the hood. Usually the hood is not tested with agents if the test results indicate leakage $>0.0001\%$. The hood was then installed on a SMARTMAN inside an agent (GB) exposure chamber, where it was leak tested again, under the conditions shown in Table 1. Then GB vapor was generated as described above and passed into the test chamber, while the breather pump operated the escape hood. The inside of the hood was monitored by MINICAMS at the eye and nose sampling ports of the SMARTMAN. The test was terminated after 65 min or at the time the concentration of agent inside the hood became $>0.008\ \text{mg}/\text{m}^3$, the concentration set as the breakthrough criterion for GB.

Table 1. GB Test Conditions

Challenge Concentration, mg/m^3	1000
Breakthrough concentration, mg/m^3	0.008
Breathing rate, L/min	40 ± 1
Breathing rate, breaths/minute	35 ± 2
Total test time, minutes	65
Temperature, $^{\circ}\text{C}$	25 ± 3
Relative Humidity, %	50 ± 5

3.2.2 HD Vapor Procedure.

An escape hood was mounted on a SMARTMAN test fixture and leak tested as described in Section 3.2.1. After the leak test, the hood was mounted on a SMARTMAN in an HD agent test chamber and leak tested as described in Section 3.2.1, except with HD agent, under the conditions shown in Table 2. The test was terminated after 65 min or at the time the concentration of agent inside the hood became $>0.003 \text{ mg/m}^3$, the concentration set as the breakthrough criterion for HD.

Table 2. HD Test Conditions

Challenge Concentration, mg/m^3	200 ± 10
Breakthrough concentration, mg/m^3	0.003
Breathing rate, L/min	40 ± 1
Breathing rate, breaths/minute	35 ± 2
Total test time, minutes.....	65
Temperature, $^{\circ}\text{C}$	25 ± 3
Relative Humidity, %.....	50 ± 5

4. PROTECTION FACTOR (AEROSOL) TESTING

A second test was performed to determine each hood's ability to protect the wearer from an aerosol threat. This test involved human test subjects donning the hood and entering a chamber filled with a challenge concentration of corn oil aerosol. This aerosol concentration is maintained between 20 and 40 mg/m^3 , and the particle size is maintained between 0.4 and 0.6 micron Mass Median Aerodynamic Diameter (MMAD). Those concentration and size ranges best simulate chemical and biological agent aerosols. While in the chamber the subjects perform exercises designed to stress the seals of the equipment. If the hood were to leak, the corn oil aerosol would enter the hood and be sampled by the laser photometers. The measure of the hood's performance for this test is the PF.

4.1 PF Testing Procedures.

The two types of hoods were tested on two different test days. Prior to each test day, the PF Test Facility personnel probed each hood so that a sample could be drawn from the oronasal region. The DefendAir had a nose cup, so a standard Army probe was inserted through the hood and into the nose cup. The Quick Mask 2000 hood has a mouth bit, so a small barb was attached to the filter component inlet to the hood so a sample could be drawn from the same air that would be breathed by the subject.

On each test day, 30 volunteers arrived at the PF Test Facility to participate in the test. Anthropometric measurements were taken from the volunteers including facial length and width and neck circumference. These measurements are shown in Appendix A. From these

measurements, 12 subjects were chosen to participate in the test. Selecting the proper size was not a concern because only one size is manufactured for either hood type. The subjects then completed volunteer agreements after the PF Test Facility personnel explained the test procedure. The subjects then donned the hood in accordance with the manufacturer's instructions, with the help of the PF Test Facility personnel. Sampling lines were then attached to the probes in hoods. Once ready, the subjects were led into the chamber where they were attached to sampling tubes connected to laser photometers located outside of the chamber. The test was then started. The subjects performed the following eight 1-min exercises:

- (1) Normal breathing
- (2) Deep breathing
- (3) Head side to side
- (4) Head up and down
- (5) Recite the Rainbow passage
- (6) Jog in place
- (7) Reach for the floor and ceiling
- (8) Normal breathing

PF Test Facility personnel communicated each exercise to the subjects from outside the chamber. When the test was complete, the subjects disconnected their sampling tubes and exited the chamber. All 12 subjects performed a trial twice for a total of 24 data points for each type hood.

4.2 PF Data Analysis.

Hood performance was quantified in terms of a PF. Just before the test was started, the photometer took a challenge aerosol concentration reading. Throughout the test, sample air was drawn continuously from within the hood. The PF was calculated by determining the ratio of the challenge aerosol concentration to the in-hood aerosol concentration as quantified by integrating the curve of the voltage output from the photometer over a time interval (1 min per exercise). A PF was calculated for each individual exercise (PF_i):

$$PF_i = \frac{\text{Challenge Concentration}}{\text{In - oronasal Concentration}} \quad (1)$$

Each PF_i for that trial was then used to calculate an overall PF for a subject (PF_o) using the harmonic average as follows:

$$PF_o = n \left(\sum_{i=1}^n \frac{1}{PF_i} \right)^{-1} \quad (2)$$

where n is the number of exercises. The PF_o is affected most by the smallest PF_i . Under the conditions of this test and the sensitivity of the photometer, the maximum PF that can be reported is 100,000. The data acquisition computer performed all calculations at the time of the test. Appendix B shows the PF_i and PF_o for each subject on each trial.

5. RESULTS

5.1 Draeger DefendAir Escape Hood.

There was no breakthrough of either GB or HD on any of the escape hoods tested during the test period. Table 3 lists the results for the PF test. The first column represents the upper bound of a PF range, with the lower bound being the PF value in the row above it. The second column represents the number of trials that fell in that range. The third column shows the cumulative percentage of all the trials. The final column shows the passing percentage at each PF in the first column.

Table 3. Draeger DefendAir PF Results

PF	Frequency	Cumulative %	Pass %
0	0	0.00	100.00
10	0	0.00	100.00
50	0	0.00	100.00
100	0	0.00	100.00
500	0	0.00	100.00
1,000	0	0.00	100.00
1,667	0	0.00	100.00
2,000	1	4.17	95.83
5,000	0	4.17	95.83
6,667	0	4.17	95.83
10,000	0	4.17	95.83
20,000	0	4.17	95.83
50,000	2	12.50	87.50
100,000	21	100.00	0.00
Total	24		

At the time of testing, there were no standards governing escape hoods for CBRN environments. Since the testing was completed, NIOSH has developed standards that require a 95% pass rate at a PF of 2,000 in the oronasal region and 95% pass rate at a PF of 150 in the hood region. The DefendAir did meet the oronasal requirement by achieving a 95.8% passing percentage at a PF of 2,000. The hood region was not sampled for this test.

5.2 Fume Free Quick Mask 2000.

There was no breakthrough of either GB or HD on any of the escape hoods tested during the test period. Table 4 lists the PF results for the Fume Free Quick Mask 2000.

Table 4. Fume Free Quick Mask 2000 PF Results

PF	Frequency	Cumulative %	Pass %
0	0	0.00	100.00
10	0	0.00	100.00
50	0	0.00	100.00
100	0	0.00	100.00
500	0	0.00	100.00
1,000	0	0.00	100.00
1,667	0	0.00	100.00
2,000	0	0.00	100.00
5,000	0	0.00	100.00
6,667	1	4.17	95.83
10,000	0	4.17	95.83
20,000	10	45.83	54.17
50,000	8	79.17	20.83
100,000	5	100.00	0.00
Total	24		

This hood also met the NIOSH oronasal requirement by achieving a 100% passing percentage. The hood region was not tested for the Quick Mask 2000.

APPENDIX A

PROTECTION FACTOR TEST

ANTHROPOMETRIC DATA

Table A - 1. Draeger DefendAir Subjects

Subject No.	Face Length, mm	Face Width, mm	Neck Circumference, mm
1	110	129	350
2	123	137	340
3	132	136	380
4	123	146	370
5	110	144	360
6	117	134	390
7	121	139	350
8	114	129	340
9	132	137	380
10	117	145	370
11	111	136	360
12	136	143	400

Table A - 2. Fume Free Quick Mask 2000 Subjects

Subject No.	Face Length, mm	Face Width, mm	Neck Circumference, mm
1	119	138	410
2	123	138	390
3	124	136	370
4	119	142	370
5	121	142	370
6	121	147	415
7	124	136	380
8	125	142	400
9	103	126	310
10	119	122	340
11	105	129	310
12	119	139	380

APPENDIX B
PROTECTION FACTOR TEST
RAW DATA

Table B - 1. Draeger DefendAir Raw Data

MASK	SUBJECT	TRIAL	PF ₀	EXERCISE NUMBER							
				1	2	3	4	5	6	7	8
G4	1	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G4	1	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G4	2	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G4	2	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G5	3	1	86,876.9	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	45,281.1	100,000.0
G5	3	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G5	4	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G5	4	2	44,740.6	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	9,192.5	99,758.0	100,000.0
G6	5	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G6	5	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G6	6	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G6	6	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G1	7	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G1	7	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G1	8	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G1	8	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G2	9	1	32,159.4	53,488.4	54,613.4	8,454.9	28,103.8	100,000.0	100,000.0	37,070.0	91,556.3
G2	9	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G2	10	1	1,728.4	991.0	3,588.5	413.2	1,956.3	11,699.8	10,473.4	11,582.9	7,034.5
G2	10	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G3	11	1	98,277.8	87,704.7	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G3	11	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
G3	12	1	54,784.5	18,133.5	67,700.4	100,000.0	100,000.0	100,000.0	100,000.0	38,300.7	100,000.0
G3	12	2	85,121.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	41,694.7	100,000.0

Table B - 2. Fume Free Quick Mask 2000 Raw Data

MASK	SUBJECT	TRIAL	PF ₀	EXERCISE NUMBER							
				1	2	3	4	5	6	7	8
Q2-1	1	1	46,020.3	100,000.0	100,000.0	44,879.7	100,000.0	23,973.1	24,254.8	34,950.0	100,000.0
Q2-1	1	2	16,458.8	100,000.0	100,000.0	100,000.0	100,000.0	3,293.4	14,498.8	15,758.8	100,000.0
Q2-2	2	1	20,852.1	100,000.0	100,000.0	100,000.0	100,000.0	3,430.6	41,541.4	69,272.5	73,229.2
Q2-2	2	2	19,005.2	100,000.0	93,124.5	100,000.0	100,000.0	3,281.8	25,000.4	52,532.7	60,783.0
Q2-3	3	1	42,272.2	100,000.0	100,000.0	100,000.0	100,000.0	10,039.1	67,342.6	47,093.3	73,772.5
Q2-3	3	2	35,732.1	54,054.7	49,451.2	51,178.0	25,233.4	16,054.1	49,291.0	38,496.9	57,328.0
Q2-4	4	1	19,590.4	100,000.0	4,525.7	53,666.4	100,000.0	32,323.5	17,462.7	19,776.2	100,000.0
Q2-4	4	2	22,058.7	100,000.0	18,624.6	100,000.0	100,000.0	5,279.3	22,899.6	33,856.8	61,158.1
Q2-5	5	1	6,586.6	100,000.0	100,000.0	100,000.0	100,000.0	1,042.8	5,839.2	29,118.0	100,000.0
Q2-5	5	2	10,456.1	100,000.0	100,000.0	100,000.0	100,000.0	1,539.9	30,826.8	30,041.6	100,000.0
Q2-6	6	1	83,844.5	100,000.0	100,000.0	100,000.0	100,000.0	46,315.6	100,000.0	72,339.2	100,000.0
Q2-6	6	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
Q2-7	7	1	82,205.6	100,000.0	90,773.0	100,000.0	100,000.0	40,886.4	87,905.1	95,542.7	100,000.0
Q2-7	7	2	37,094.2	100,000.0	100,000.0	100,000.0	100,000.0	7,141.5	100,000.0	63,938.1	100,000.0
Q2-8	8	1	22,108.9	100,000.0	100,000.0	89,835.6	42,927.3	10,170.6	8,600.6	22,516.6	20,655.9
Q2-8	8	2	18,892.4	71,934.3	47,330.1	33,846.2	23,225.4	4,911.5	17,191.9	28,682.7	52,127.8
Q2-9	9	1	13,748.2	100,000.0	100,000.0	100,000.0	100,000.0	2,648.0	6,932.3	100,000.0	100,000.0
Q2-9	9	2	24,641.6	100,000.0	100,000.0	100,000.0	100,000.0	5,609.1	11,577.9	100,000.0	100,000.0
Q2-10	10	1	14,334.8	77,566.2	12,411.8	41,964.1	38,102.7	16,113.9	3,440.8	20,082.5	82,886.6
Q2-10	10	2	14,831.2	74,870.9	100,000.0	100,000.0	100,000.0	2,884.3	10,962.1	30,538.2	39,412.8
Q2-11	11	1	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
Q2-11	11	2	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0	100,000.0
Q2-12	12	1	15,744.1	100,000.0	100,000.0	100,000.0	100,000.0	12,047.4	3,085.7	22,020.1	63,988.3
Q2-12	12	2	12,409.1	30,948.8	25,993.2	36,014.4	30,912.8	3,385.6	9,370.8	14,345.7	23,807.5

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