# OPEN AND CLOSED CIRCUIT/REBREATHER TECHNOLOGIES FOR ADVANCED NBC COLLECTIVE PROTECTION

**Richard Greib**
General Dynamics Land Systems
38500 Mound Rd, Sterling Heights MI, 48310
Phone: 586-825-5436

## INTRODUCTION

The recent terrorist attacks and documented use of Anthrax/Biological Weapons on citizens of the United States has significantly elevated the awareness of the potential use of Nuclear, Biological and Chemical (NBC) weapons and Toxic Industrial Chemicals (TICs) as a real threat. Current filtration technologies (Carbon, Pressure Swing Absorption, Catalytic Oxidation-CATOX) used to protect against these threats have a limited capacity and a limited spectrum of agents that can be removed effectively. Carbon based filtration systems require significant logistics support, are costly, and could require frequent filter replacement if attacked. General Dynamics Land Systems (GDLS) is currently developing several advanced NBC Collective Protection systems that incorporate new technologies/methodologies that will significantly improve NBC system performance and protection without the limitations and burdens of current systems.

One system currently being developed by GDLS provides superior performance over existing NBC collective protection technologies. This system will provide Continuous, Full Spectrum Protection against all known and future NBC threats and all Toxic Industrial Chemicals without filters (Open & Closed Circuit/Rebreather). Initially developed for incorporation into combat vehicles, (legacy & future systems), this fully scaleable technology can be applied in aircraft, ships, battlefield command posts, mobile/fixed shelters, and building collective protection systems.

## REQUIREMENTS

Objective NBC Collective Protection System requirements for several recent vehicle programs specify that the NBC filtration system must withstand two dual agents challenges per day for a 30-day mission without the need to change filters. The composition of the challenges and the definition of the agent classes/ peak challenge concentration are identified in Tables 1 and 2, respectively.

TABLE 1. Daily Dual Challenge Composition

| | AGENT 1 | AGENT 2 |
|---|---|---|
| CHALLENGE 1 | Medium Volatility Agent | High Volatility Agent |
| CHALLENGE 2 | Low Volatility Agent | High Volatility Agent |

The first challenge consists of one medium and one high volatility agent. The second challenge consists of one low and one high volatility agent.

TABLE 2. Agent Classification

| VOLATILITY | TYPE |
|---|---|
| High | Blood, Choking and Organofluorines |
| Medium | Nerve agents (GB,GD) except VX |
| Low | VX and Blister Agents (HD) |

The accumulated dosage for each specified challenge is identified in Table 3. The total accumulated/integrated dosage of each type of agent is given in the last row of this table.

TABLE 3. Threat Concentration/Dose Profile

| | LOW VOLATILITY | | MEDIUM VOLATILITY | | HIGH VOLATILITY | |
|---|---|---|---|---|---|---|
| Time (Min.) | Concentration ($mg/m^3$) | **Dosage** ($mg\text{-}min/m^3$) | Concentration ($mg/m^3$) | **Dosage** ($mg\text{-}min/m^3$) | Concentration ($mg/m^3$) | **Dosage** ($mg\text{-}min/m^3$) |
| 0 | 225 | 0 | 7500 | 0 | 50000 | 0 |
| 0.5 | 225 | 112.5 | 7500 | 3750 | 50000 | 25000 |
| 0.6 | 50 | 112.5 | 110 | 3750 | 2000 | 25000 |
| 10. 0 | 50 | 587.5 | 110 | 4795 | 2000 | 44000 |
| 10.1 | 5 | 587.5 | 1 | 4795 | 0 | 44000 |
| 60.0 | 5 | **837.5** | 1 | **4845** | 0 | **44000** |

## PROBLEM STATEMENT

Current Nuclear, Biological, and Chemical (NBC) air filtration systems can not meet the new objective NBC threat requirements for military systems or the newly identified requirement for protection against Toxic Industrial Chemicals (TICs). Conventional carbon based NBC filters have a limited capacity for several of the chemical agent threats, specifically the high volatility threats. Comparing the total accumulated dosage of High Volatility Agent delivered in each challenge (44,000 $mg\text{-}min/m^3$) with the rated filter capacity of 80,000 $mg\text{-}min/m^3$ for CK, it can been see that the M48A1 filter capacity is just under two full challenges. Because of this limited capacity, carbon filters, by doctrine, must be replaced after each high volatility agent challenge. For a typical M1A1 Main Battle tank which uses 2 M48A1 filters, the 30-day mission cost for NBC filter replacement would be excess of $90,000 per vehicle. This could potentially result in a significant expense and a logistic burden in order to sustain mission capability for the numerous vehicle systems required to perform on the NBC contaminated battlefield.

In addition, several TICs can rapidly break through the filters. This specifically includes those gases like carbon monoxide, carbon dioxide, and ammonia. In addition, the efficiency of the impregnants deposited on the carbon for reacting with the High Volatility Chemical warfare threats/TICs diminish as a function of water/humidity exposure and time. Carbon based filters must be replaced frequently and are very expensive. Thus, NBC collective protection system using carbon based NBC filters is both limited, extremely costly and imposes a significant logistics and maintenance burden to sustain NBC collective protection.

## SYSTEM DESCRIPTION

GDLS has developed a new NBC Collective Protection System that does not have the capacity, environmental or threat limitations of carbon based filters. In addition, it does not require replaceable filters or adsorptive beds. This system is capable of providing continuous, full spectrum protection against

all known/projected NBC threats and Toxic Industrial Chemicals. The GDLS Modular Air Revitalization System (MARS), illustrated in Figure 1, provides this level of protection through the use of an advanced oxygen generation and carbon dioxide scrubbing system used to support the crew located in a closed/sealed capsule environment. Performance is optimized via the closed capsule crew compartment, now possible with advanced vehicle designs using weapon systems located remotely from the crew compartment. The Open Circuit/Rebreather system design permits selective oxygen extraction from the ambient environment yet provides a physical barrier against the penetration of all other molecular gases (contaminants or naturally occurring).

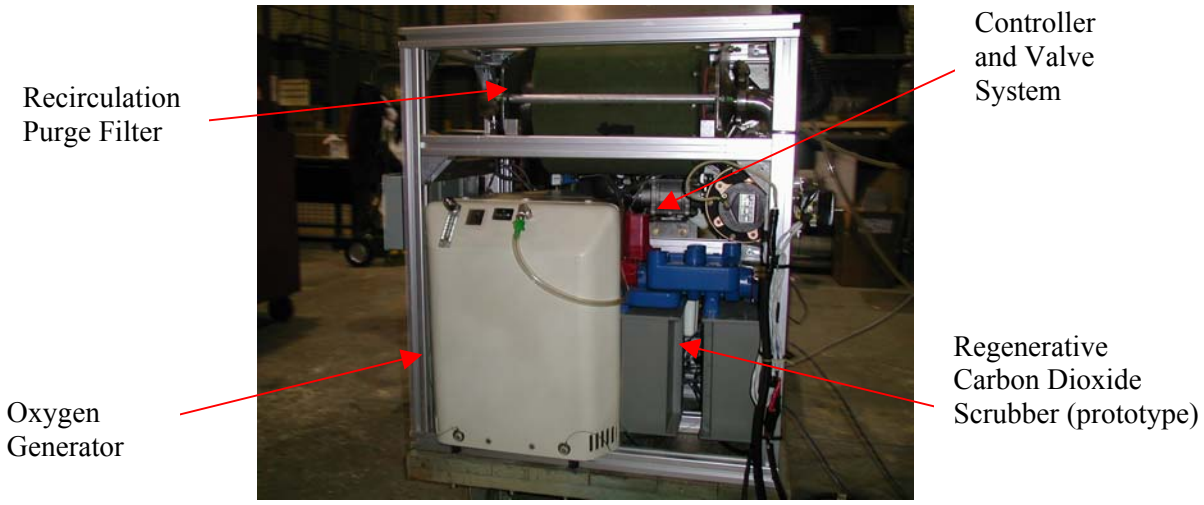


Figure 1. Modular Air Revitalization System (MARS).

A crew compartment purging capability is an integral part of the system, and is used to remove contaminants that may be deposited/transferred into the compartment before protective posture is assumed. This purge capability also eliminates water vapor, body odors, and gun gas fumes that may be discharged into the crew compartment during operation. Closed loop control of the physiological gas concentration is provided by GDLS's respiratory gas control and sensor system.

## DISCUSSION

The MARS system illustrated in figure 1 utilizes Open Circuit/Rebreather technology being developed by GDLS and its technology partners. Closed Circuit/ Rebreather technologies for MARS are also being developed and can be applied as required. Illustrations of both conventional filtration systems, Open and Closed Circuit/Rebreather technologies are illustrated in figure 2.

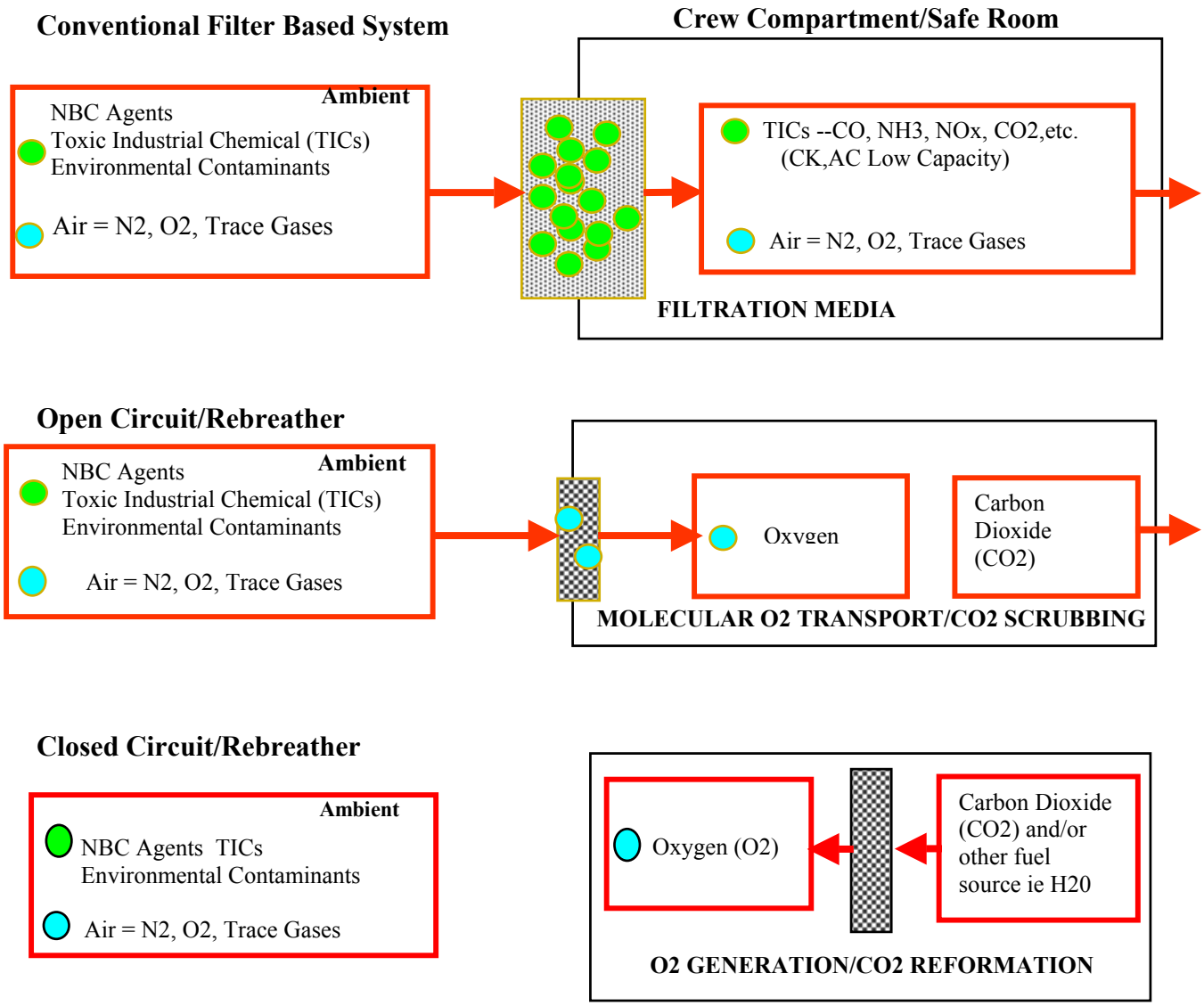


Figure 2. Collective Protection System Comparison.

Conventional filtration systems require that all the air required to maintain overpressure and sustain the crews physiological requirements are filtered from contamination. Significant quantities of air can be required to maintain overpressure in legacy vehicle systems. This places a large burden on the filters with respect to agent loading, a function of agent concentration, duration of threat, and airflow rate of the system. Similarly, a large burden is also placed on the thermal management system for heating or cooling the large amount of clean air flow that is required to sustain overpressure. This burden can be significantly reduced by minimizing the airflow rate required to maintain overpressure and by controlling vehicle leakage. The lower limit being the minimum airflow required to support the respiratory demands of the crew for oxygen consumption and carbon dioxide purging.

Open and Closed Circuit/ Rebreather system only differ in the way oxygen is obtained for crew respiration. Both system designs incorporate a carbon dioxide scrubber, purge filter and control/sensor

system. Regenerative carbon dioxide scrubbers are used inside the sealed compartment to maintain concentrations below levels that would induce physiological distress and provide continuous operation.

In the open circuit/rebreather systems, the oxygen is extracted from the ambient air surrounding the vehicle. Oxygen is delivered into the crew compartment at a sufficient rate to replace the oxygen physiologically consumed by the crew/occupants. This can be accomplished with several different technologies to include pressure swing absorption (PSA) systems using selected molecular sieves for oxygen production (ie. On-Board Oxygen Generators- OBOGS). This technology would have similar power, filtration/breakthrough and size limitation of PSA systems developed for NBC applications. GDLS is using a unique non-filtering process, which selectively extracts oxygen molecule from the ambient air, transports the oxygen ions across solid membrane and produces a pure oxygen product. This results in superior NBC protection as a physical barrier is provided against all other molecules.

In closed circuit /rebreather systems, oxygen is generated from a fuel source carried on the vehicle. This results in total isolation from the ambient contaminated environment and also provides a physical barrier to contamination transfer. In addition, it is similar in concept to the systems used in submarines and space craft/stations today. Electrolysis is used in submarines to produce oxygen from water. The Sabtier process is used in the space craft/stations for the conversion of carbon dioxide into oxygen. Similarly, submarines and space craft/stations utilize carbon dioxide scrubbers and air quality management treatments to prevent the accumulation of toxic gases, unpleasant odors and water vapor. GDLS has developed a novel concept for reforming CO2 into O2 that does not have the power burden associated with the two aforementioned closed circuit technologies and is currently pursing development.

The current configuration of the MARS incorporates a novel Open Circuit/Rebreather technology with the focus on respiratory gas control in a sealed crew compartment. In addition, this system does not utilize/require replaceable sorbant filters/beds eliminating the logistics burden of filter/bed replacement and the potential for filter/bed breakthrough or defeat of the filtration system. Air within the compartment is purged of other contaminants that may be introduced. Since the air in the crew compartment is revitalized rather that discharged a significant reduction in power for overpressure and thermal/environmental management can be obtained.

With the MARS technology, oxygen production levels can also be controlled and the partial pressure of oxygen slightly elevated to increase alertness and to prevent fatigue during periods of high physiological stress. Levels are monitored by the sensor system to ensure that safe levels for human exposure and fire hazard prevention are not exceeded.

## TECHNOLOGY MATURITY AND VALIDATION

The superior survivability, performance, integration, life cycle cost and logistics burden attributes provided by this system resulted in the Open and Closed Circuit/Rebreather technology receiving a *high potential* ranking in the Joint Services Collective Protection Front End Analysis (conducted in April 2001). The Front-End Analysis (FEA) trade study focused on identifying the highest value/potential collective protection technologies for Joint Services investment/development over the next ten years. As a result of the FEA ranking, GDLS's technology has been awarded a multi-year contract for the tech base development addressing Open and Closed Circuit/Rebreather systems.

Preliminary testing has been completed demonstrating the functionality of the prototype, specifically the physiological/respiratory gas control in a sealed vehicle crew capsule. This has been accomplished via a human physiological simulator, which can be adjusted for number of crew/personnel and their average metabolic rate. Initial tests have also been conducted which successfully demonstrated

that oxygen extraction is possible from a TIC contaminated air stream without any cross contamination. TIC contaminant testing is continuing with selected contaminants from the ITF-25 list. A testing program to validate survivability and performance with selected live agents (FM 3-9 Potential Military CB agents) is underway with preliminary results expected in early 2003. Test validation is considered low risk as the materials and transport mechanism is expected to survive NBC agent and TIC exposure without performance degradation.

## CONCLUSIONS

The open and closed circuit /rebreather technology shows significant promise being the first technology that could provide Continuous, Full spectrum NBC/TIC protection without replacing filters. This is a significant accomplishment in improving military vehicle operational readiness, mission performance and survivability. Unencumbered by filters that require replacement after each High Volatility Agent challenge, the vehicle systems will be able to maintain their operational tempo unimpeded when confronted with multiple agent attacks. Furthermore, the logistics system will not be burdened with moving NBC filters to these vehicles when fuel and ammunition are more critical to the mission completion. The survivability and readiness levels provided by Open and Closed Circuit/Rebreather technology will provide a decisive edge to the war fighter forced to fight on the NBC Contaminated Battlefield.

## ACKNOWLEDGMENTS

This program has been conducted exclusively under GDLS Internal Research and Development (IRAD) funding. Significant contributions have been made by Ms. Janet Iwanski, and Mr. James Estes in the successful development, fabrication and demonstration of the MARS technology demonstrator. Other noteworthy contributions have been made by Dr. M. Lindell in the analytical/developemental support, Mr. Mark Paquette and Mr. Nathan Tison in supporting the flow analyses/design and Mr. Mark Pirkola in developing the controller system. Mr. Ed Hill has also made major contributions in overall support, which has directly contributed to the success/visibility of this program.

## REFERENCES

1. R.J. Greib “Applied NBCCS Programs for Collectively Protected Tracked and Wheeled Military Vehicle Systems,” General Dynamics Land Systems Division, WorldWide Chemical Conference XV and NBC Operations Symposium, Sponsored by The US Army Chemical School and ADPA/NSIA, 24-27 June 1997.
2. Army Regulation (AR) 70-75, “Survivability of Army Personnel and Material”, Headquarters- Department of the Army, 10 January 1995.
3. NBCCS Criteria for Army Materiel, U.S. Army Nuclear and Chemical Agency, 12 August 1991.
4. Field Manual (FM) 3-5 NBC Decontamination, Headquarters- Department of the Army , 17 November 1993.
5. Field Manual (FM) 3-9 Potential Military Chemical/Biological Agents and Compounds, Headquarters- Department of the Army, Navy, Air Force , 12 December 1990.
6. Test Operation Procedures (TOP) 8-2-111, NBC Contamination Survivability, Small Items, TECOM, July 1991.
7. Test Operation Procedures (TOP) 8-2-510, NBC Contamination Survivability, Large Item Exteriors, TECOM, July 1991.
8. ITF-25--Toxic Industrial Chemical List.
9. Filter, Gas- Particulate ( 100CFM) Hybrid Collective Protection Equipment, Chemical Systems Laboratory Purchase Description, ED46044, Dated 25 May 1982.