The evolution of Closed Circuit Breathing Apparatus used by Mines Rescue Services – South Africa

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Abstract: The paper systematically describe the evolution of long duration breathing apparatus used by Mines Rescue Services in South Africa over the past 78 years. The author elaborates on the process followed to select and implement the latest technology in breathing apparatus into Mines Rescue Services.

Introduction

Like so many of her beneficial provisions, Mother Nature herself, supplied the first smoke filter in the shape of a fireman's moustache and whiskers. It is recorded that in former days in some countries, a face full of whiskers was an essential requirement of every fireman. At the outbreak of a fire, his orders were, "Wet your beard, take it between your teeth, and in you go through the smoke!" It was firmly believed that the whiskers filtered or at least modified the air surrounding the wearer – whether that atmosphere was vitiated, polluted or actively noxious.

The need for devices to protect the respiratory organs dates back to medieval times. Up to the 18th century there are on record numerous ingenious designs of breathing apparatus, known today as primitive air filters. A few of these are worthy of mention, they are as peculiar in operation as their names imply:

- Breathing from under a heavy jacket design
- The parson's nose, a fabric filter attached to the nose opening
- Bellows in the boots, or under the armpits models
- The vinegar type
- Glass bottle and straw respirator.

Their limitations can be well understood and were useless in a noxious or oxygen deficient atmosphere.

To overcome the limitations, research in the 17th Century produced a breathing apparatus that rendered the wearer independent of the surrounding atmosphere. Fresh air was pumped into a large leather bag using a bellows. The wearer inhaled this air, and the expired air containing carbon dioxide passed through a solution of lime water. The residue was fit to breathe again. The apparatus was limited to about five minutes. A variety of oxygen producing chemicals was tested during the early days of the industrial revolution in Great Britain.

Primitive Breathing Apparatus

Salt petre, acids, peroxides and oxylithe were but a few. This era of development can rightly be referred to as the embryo for the development of closed circuit breathing apparatus. Many designs were made, tested and rejected during the 18th and 19th centuries.

The first compressed oxygen breathing apparatus:

The evolution of oxygen breathing apparatus goes back to the mid 19th century. In 1853 a Professor Schwann developed the Aerophor apparatus.

It consisted of a mouthpiece, regenerated cartridge, breathing bag and two oxygen flasks; this basic combination has remained unchanged to this day.

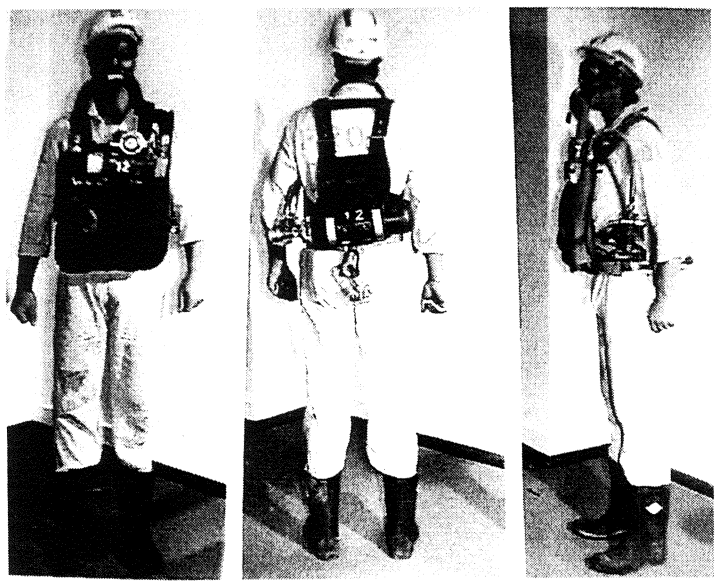
Oxygen feed was manually activated by the wearer at his discretion. One of the greatest difficulties to overcome was raising the oxygen pressure in the flasks. It was not until the beginning of the 20th century that pressure in the flasks could be raised to 120 bar. All mining countries in Europe proceeded to develop breathing apparatus fitted with a pressure reduction valve and a constant oxygen dispenser.
To reduce the very high breathing resistance, injectors were introduced into the apparatus, operated by a constant oxygen outflow.

The first practicable self-contained breathing apparatus was developed by an English marine engineer, Henry Fleuss in the late 1870's. Fleuss patented his invention in 1879. A license for commercial manufacture of the apparatus was awarded to Messrs Siebe Gorman & Co in England. At that time Siebe Gorman were engaged in the manufacture of submarine diving suits and equipment.

The Fleuss apparatus was tested by the inventor and others in afterdamp to explore Seaham Colliery (United Kingdom) following the explosion in 1880, where one hundred and sixty four lives were lost. Further tests were conducted in an irrespirable atmosphere at Killingworth Colliery (United Kingdom) in 1882 following another explosion of flammable gas. Fleuss also tested his apparatus underwater in the Severn Tunnel flooding in 1882.

In England, the first mines rescue station was established in 1902 in Tankersley, Yorkshire by the local Coal Owners Association. By 1907, following the tragic loss of 1,100 miners after a gas and coal dust explosion, the original Fleuss apparatus had been improved by the inventor in conjunction with Dr.Hill and Mr.R.Davis of Siebe Gorman. The outcome was known as the Fleuss Davis Apparatus and marketed by Siebe Gorman under the trade name "Proto". Hence the well known Siebe Gorman Mark IV "Proto" breathing apparatus was born. It was used in South Africa exclusively from the inception of the Rescue Services in 1925 until replaced by the Drager BG 174 in 1980.

Siebe Gorman Mark IV set used from 1925 to 1980



Further development of Closed Circuit Breathing protection:

Another type of breathing apparatus was the invention of a breath-controlled dispenser, the so-called automatic lung. The first truly automatic regenerative apparatus was developed by a Dr. Gibbs in America in 1917. It had an oxygen supply of 378 liters. The compressed gas flask was made of steel, had a volume of 2.8 liters and charged to a pressure of 135 bar. It had a mass of 15 kilograms and lasted for three hours. A problem was the nitrogen build-up in the set due to the low purity of oxygen at around 95%.

Instructions to users, such as squeezing the breathing bag before use and starting the breathing cycle by breathing in. This danger was to be ruled out when manually operated overpressure bleeder valves were inserted on the exhalation side or in the mouthpiece.

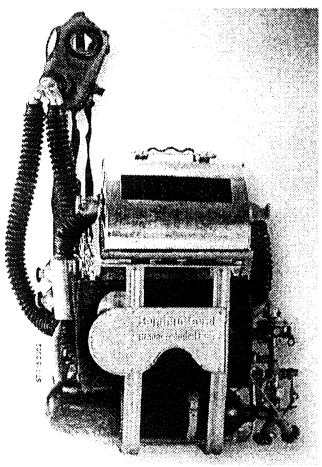
The wearer had to open the valve briefly during the exhalation phase at regular intervals, so as to flush out the nitrogen air. The invention of the automatic lung

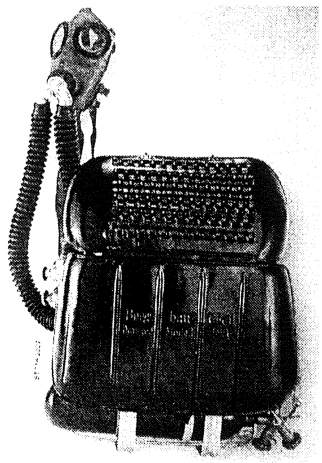
demand valve had a significant effect on the development of breathing apparatus. Injector types were progressively replaced by automatic lung dispensers.

In the early 1930's Auergesellschaft GmbH (later known as MSA Auer) developed the MR 11\32 and Dragerwerk AG, the BG 160A. Both had automatic lung valves. To avoid nitrogen concentration in the breathing circuit, a constant oxygen feed of over 1.5 liters per minute was provided. An oxygen cylinder of 2 liters at 150 bar provided 2 to 3 hours operating time.

Following the Grimberg Colliery fire in 1946, the German Mines Rescue Committee resolved that oxygen breathing apparatus of longer duration was absolutely essential. Drager was the first to comply with the model BG170\400, the so-called long distance apparatus.

The 1924 Draeger BG





By raising the oxygen pressure from 150 to 200 bar and eliminating the constant feed, with out increasing the mass of the apparatus, provided 4 hours at a heavy workload, 6 to 8 hours light work and up to 12 hours at rest. After restoring their factory in Berlin, which had been damaged in the Second World War, Auer released a competitive product in 1954, the model MR54\400. The ever present threat of nitrogen build up in closed circuit breathing apparatus resulted in additional complex safety devices, which made maintenance and testing labour intensive. The need for improved oxygen purity and apparatus of simpler design became imperative.

In 1955 both Auer and Drager developed models Auer 56\400 and Drager 13G172, using most of the components of the above apparatus. These new models, equipped with automatic lung demand and 1.5 liters per minute constant feed became standard issue to mine rescue teams for over a decade.

Although breathing apparatus had become technically advanced, the need for lower overall mass and lower inhalation temperature, led to the development in 1963 of the Drager BG174 closed circuit oxygen breathing apparatus. A redesigned housing, pressure reducer and combined valve box with automatic lung demand brought the mass down to 14.5 kilograms. Inhalation temperature was reduced by about five degrees Celsius.

The BG174 was soon accepted and became the standard apparatus for mines rescue teams worldwide.

Liquid Oxygen Breathing Apparatus:

The liquid oxygen breathing apparatus is the third group of breathing protection devices. In 1906, Otto Sueb, an engineer from Ostrava, developed a "liquid air device" using 60% oxygen and named it the Aerolit. A German company improved on the design and manufactured the devices.

In 1923 Drager AG built its first liquid oxygen apparatus and named it Dragerolith. The construction and operation of all liquid oxygen devices was the same. A storage container with asbestos wool, free of all organic substances, filled with liquid oxygen. To avoid rapid evaporation of the oxygen, the container was well insulated. In the first models the exhaled air was not regenerated, but ducted to the atmosphere, as with a compressed air breathing apparatus.

Further developments incorporated a regeneration cartridge and breathing bag through which the exhaled air was ducted before passing through a space between the storage container and insulation. This precaution accelerates oxygen evaporation while cooling the inhalation circuit. The evaporated oxygen and the cooled exhaled air are brought together and coupled to the wearer via an inhalation tube. Asbestos was replaced by a mineral fiber as an absorption medium for the liquid oxygen.

In the 1960's the Siebe Gorman model Aerorlox liquid oxygen apparatus was introduced. In the late 1960's the Aerorlox was issued to black task force members. Its disadvantages outweighed the advantages resulting in it's phasing out in favour of closed circuit compressed breathing apparatus

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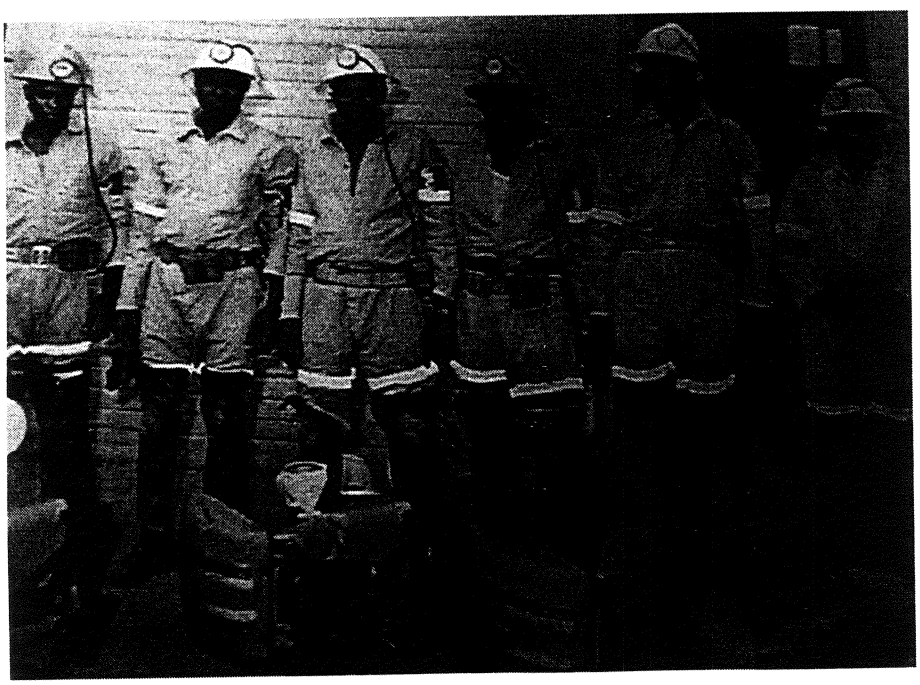
Rescue Assistants with Aerorlox apparatus



Dräger BG 174 Breathing Apparatus

The model BG174 was developed in 1960 by Drägerwerk in Germany, specifically for use in mines. The apparatus is a fully automatic, lightweight breathing apparatus which renders the wearer entirely independent of the surrounding air. It is a self contained closed circuit set, using compressed medical grade oxygen with regeneration of the expiratory air. Controlled by valves, the breathing air flows through the apparatus in a closed uni-directional circuit.

The apparatus provides the wearer with 3.5 to 4 hours of oxygen at a moderate workload.

The main advantages of the BG174 over its Siebe Gorman predecessor are:

- the backpack configuration, allowing better cooling of the front of the wearers' body,
- improved carbon dioxide absorption,
- full facemask with speech diaphragm,
- cooler inspired air,
- automatic lung demand
- and low oxygen pressure warning

The main disadvantages are:

- high operating costs,
- lack of positive pressure oxygen flow
- and lack of an integrated breathing air cooler.

The BG174 provided the mining industry and Mines Rescue Services with twenty years excellent service. Unfortunately it did not comply with EN and NIOSH accreditation in Europe.

Field trials on other Long Duration Apparatus

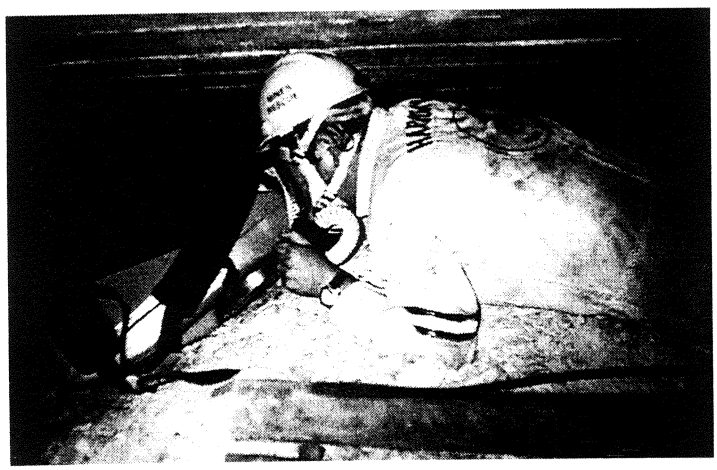
In 1996 it was decided to test all possible Long Duration Closed Circuit Breathing Apparatus which complied with the EN standards.

The first apparatus which was tested in South Africa was the Biomarine Biopak 240. Trails were concluded on 10 Biopaks by a rescue team from the Welkom Rescue Station. The sets were subjected to a variety of situations and conditions in haulages and stopes in metalliferous mines during seven underground fires. While the team reported positively on the overall breathing comfort, concern was expressed relating to the size of the apparatus when negotiating confined spaces.

Furthermore the sets were subjected to "effort" tests, the results of which proved that users' oxygen consumption was much higher than with the BG 174, this being the result of the additional mass.

Comparison between size of Biopak 240 and Dräger BG 174

"Effort" test on Biopak 240



During 1997 basic wearer tests were conducted on the Auer Air Elite. This is a 2-hour closed circuit, Chemical oxygen apparatus. Although tests revealed that ergonomics and breathing comfort were excellent, the apparatus would not be financially viable due to the enormous cost of replacing the chemical oxygen canisters after each use.

Mines Rescue Services identified a potentially suitable replacement for testing, namely the Dräger BG 4.

Dräger BG 4 - The new generation

The Dräger BG 4 is the new generation of closed circuit breathing apparatus with a 4 hour usage period and includes a Positive Pressure Demand System for extra safety and protection when used in toxic environments.

The BG 4 is the successor of the Dräger BG 174 and it complies with EN 145 and Niosh CFR 30. Modern material plus micro-electronics makes for a comparatively low mass. The ergonomically shaped carrying frame with the new comfort harness system ensures perfect wearer comfort. Breathing comfort is afforded by a flow-

sensitive Carbon Dioxide absorber with Soda Lime and the integrated breathing air cooler reducing the inhaled breathing air temperature for maximum wearer comfort.

Mines Rescue Services in South Africa opted to test the Dräger BG 4 IP (International).

Prior to the commencement of field trails, numerous shortcomings of this apparatus were identified and consequently modified to suit our mining conditions.

In April 1998 a nine-man rescue team received induction training under the direction and management of the manufacturer and Mine Rescue Services staff. This training embraced all theoretical and practical disciplines, as well as the formulation of procedures and controls. On conclusion of the course each brigadesman was competency tested.

Dräger Staff and Rescue team during initial training

Field Trails

Pre-determined criteria was laid out, such as:

- Breathing resistance
- Inhalation temperature
- Reliability of electronic monitron
- Overall durability
- Ergonomics such as size and wearer comfort

The apparatus was extensively tested during several underground fires in extreme environmental conditions (temperatures as high as 95°C). Breathing resistance and inhalation temperatures on each occasion proved to be more than satisfactory. The electronic monitron proved to be robust and reliable.

There were signs of fatigue on the lids and remedial steps were required.

Considering that the BG 4 apparatus weighs slightly more than the BG 174, it is far more comfortable due to the broad padded body belt that transfers the load from the shoulders and distributes it evenly on the hips.

The rescue team expressed concern that there are too many small parts that could be mislaid during washing and assembling procedures. It was suggested that this could be overcome by possibly incorporating several parts into sealed units.

The team stated that the BG 4 is probably the most advanced closed circuit breathing apparatus in the world in terms of technology and comfort.

Tests continued and in June 1999 sufficient data had been gleaned regarding breathing resistance, ergonomics and physical strength of the apparatus required for South African mines.

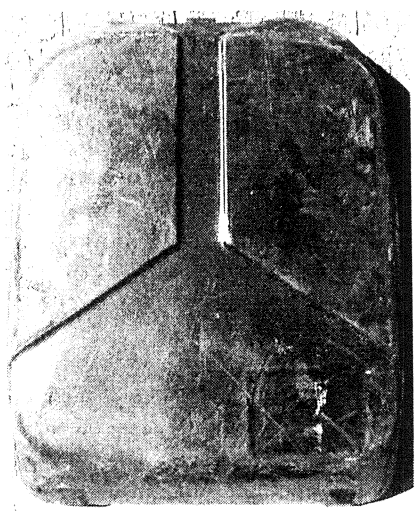
Several changes were recommended. Particular consideration was given to the physical construction of the various components, as wearer tests had already provided satisfactory breather comfort results.

Additional changes implemented were:

- Re-enforcement ribs on protection lid
- Easy connectors (Bayonet rings) on breathing tubes
- Re-enforcing rings over breathing tubes
- Additional space provided at minimum valve for ease of assembly
- Addressed the concern about the loose components in the relief valve and saliva trap.

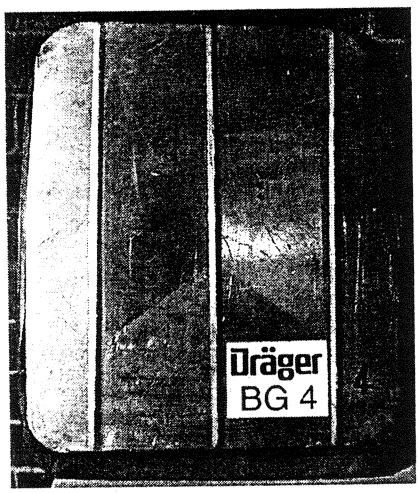
Tests conducted on various types of protection lids:

1. **Original BG 4 lid**

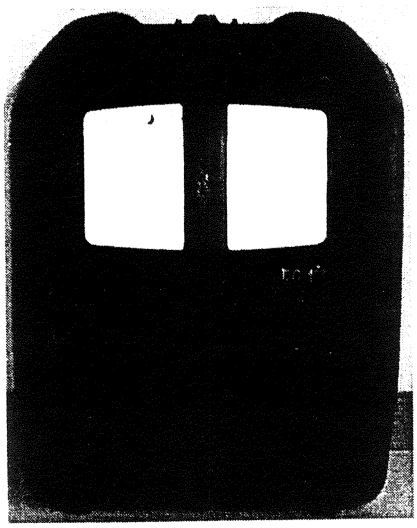


2. **Original lid with metal covering**

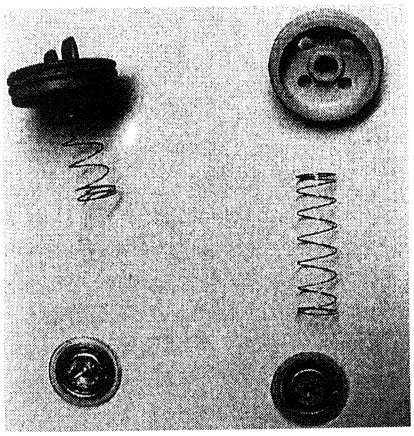
3. **Lid made from metal**



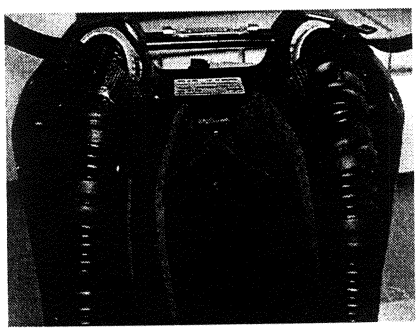
4. **Lid currently in use made of glass fibre re-enforced Duroplast**



5. **Reduction in number of loose components on the Relief and Saliva valves.**



6. **Re-enforcing rings on breathing tubes**



Implementation of Dräger BG 4 IP

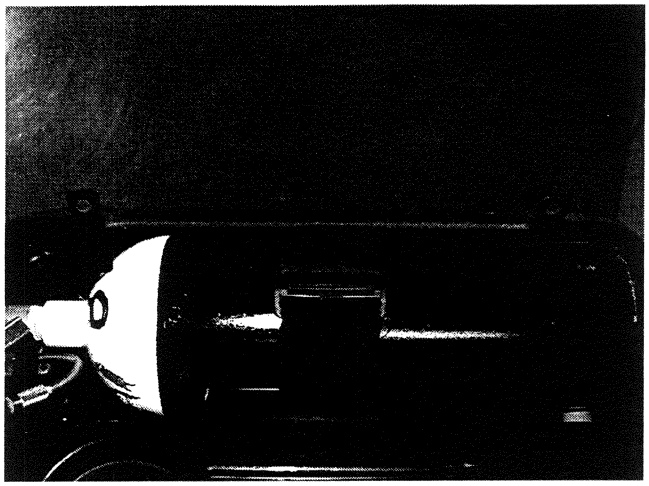
At the end of the year 2000 there were approximately 1000 brigadesmen in South Africa receiving training at 3 rescue stations across the country. It was decided to gradually phase the new apparatus in by changing the apparatus at the Carletonville Rescue Station in 2001, then the Welkom Rescue Station in 2002 and finally the Evander Rescue Station in 2003. The stations were ranked from the most active to the least active in order that the BG 4 could be utilized as much as possible during underground fires.

The BG 4 was extensively utilized during 2001 and 2002 and performed well in the very harsh underground conditions. Areas were identified where the apparatus could be improved and the following changes were requested:

- ✓ The lugs on the carry assembly where the cover clips into, to be replaced with stainless steel lugs.
- ✓ All refillable cartridges to be of the transparent types which will increase the safety of the apparatus as the wearer can visually inspect the contents of the cartridge.
- ✓ The angle connector and L-connector on the oxygen reducer to be replaced with steel connectors.
- ✓ The connection piece on the Panorama Nova face mask to be strengthened.

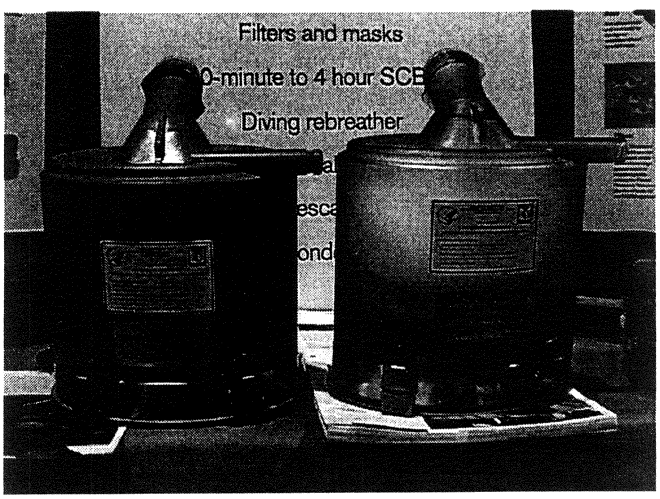
✓ The holding clip for the drain valve must be re-designed as the screw that holds the clip to the back plate damages the drain valve.

1. **Original lugs for lid.**

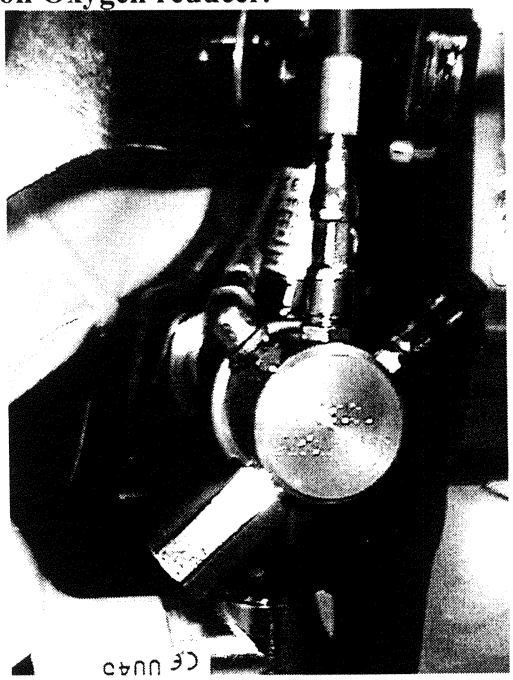


2. **New stainless steel lugs.**

3. **Transparent refillable cartridge (right hand).**



4. **Steel connectors on Oxygen reducer.**



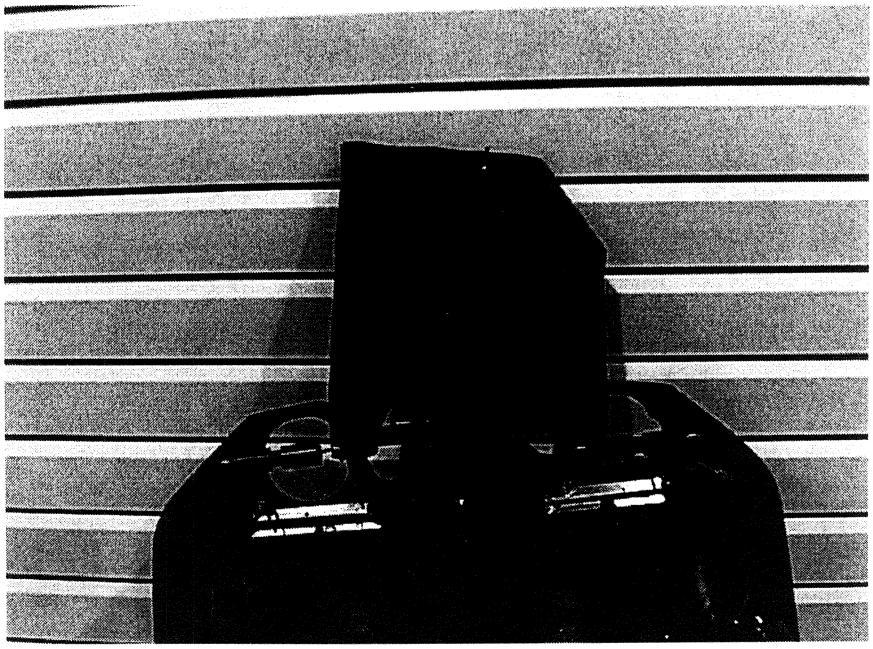
5. **Clip on Panorama Nova Face mask.**

To prevent the drain valve from been damaged, the cylinder cradle will be elevated by changing the current four screws and installing spacers below the cradle.

Mines Rescue Services developed its own emergency procedures to be followed in the unlikely event of a depleted oxygen cylinder as well as when a brigadesman collapses in a toxic environment.

Wearer tests indicated that the heat from the cartridge could cause some discomfort for the wearer on his back. Mines Rescue Services has made a special Kevlar heat pad available.

Heat pad to be inserted between cartridge and carry frame.



Statistics regarding Mines Rescue Services

The number of rescue teams in South Africa decreased from 191 teams in 1988 to 131 teams in 2002. The number of brigadesmen also decreased from 1314 to only 880 over the same period. (Table 1 and Table 2)

Metalliferous fires reported ranged between a maximum of 147 fires per annum to a minimum of 54 fires per annum. The number of rescue teams used during these fires ranged between 1040 per annum to 284 per annum. (Table 3 and Table 4)

Utilization of the BG 4 during underground fires.

During 2001 with the implementation of the BG 4 at the Carletonville Rescue Station, 68 sets were used by 12 rescue teams during 6 underground fires.

In 2002 the Welkom Rescue Station converted to the new apparatus and in that year a total of 1320 sets were used by 240 teams during 51 fires.

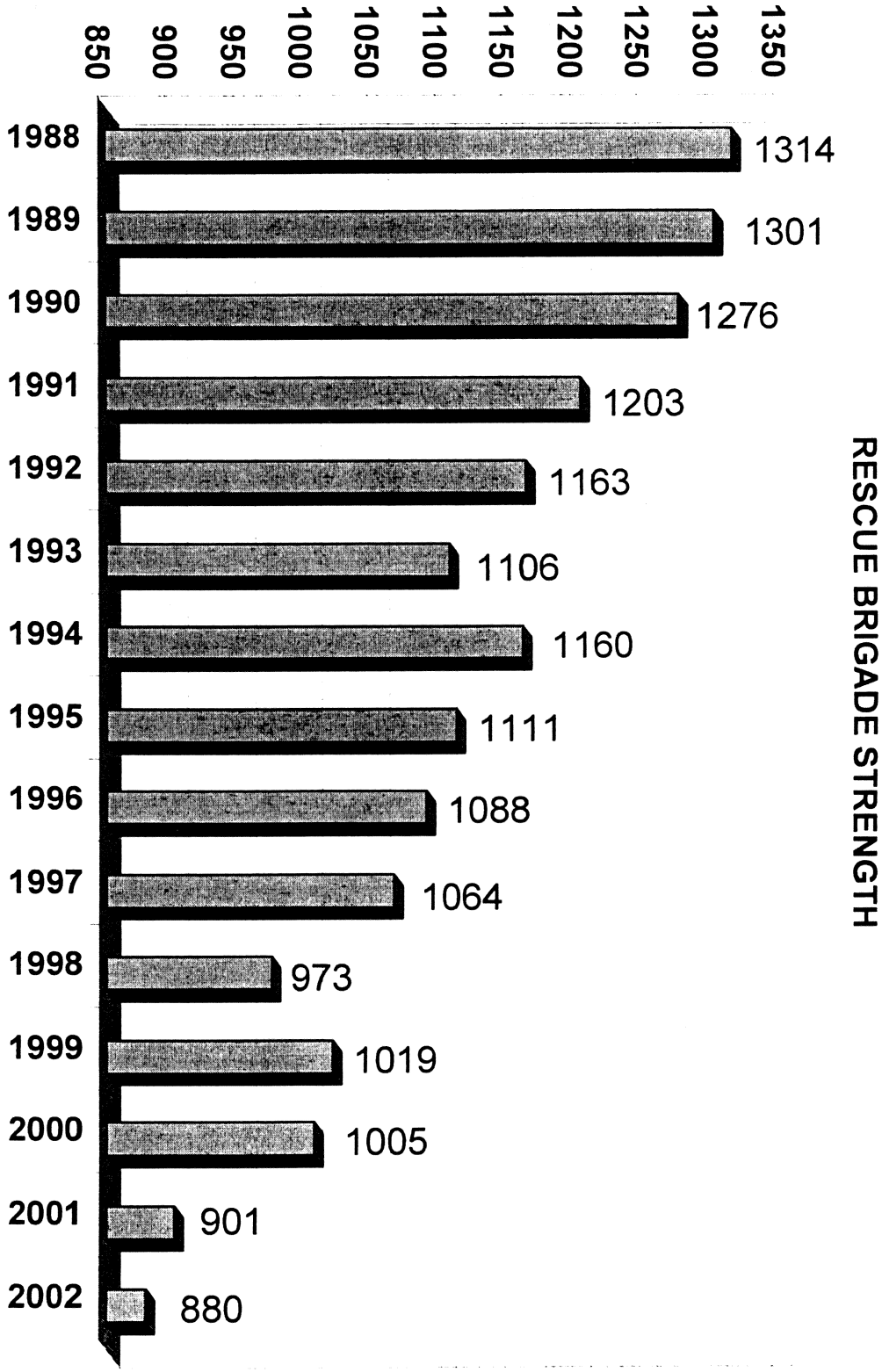
The Evander Rescue Station is in the process of changing to the BG 4 and to the end of August 2003 Mines Rescue Services have used 3556 sets (635 teams) during 41 fires.

In total the number of sets used since inception is 4944 used by 887 teams during 98 fires.

Conclusion.

The Dräger BG 4 has proved itself to be a worthy successor for the legendary BG 174. Mines Rescue Services in conjunction with Dräger will continue to evaluate the performance of the apparatus and new technology such as the Body Guard will be tested.

TABLE I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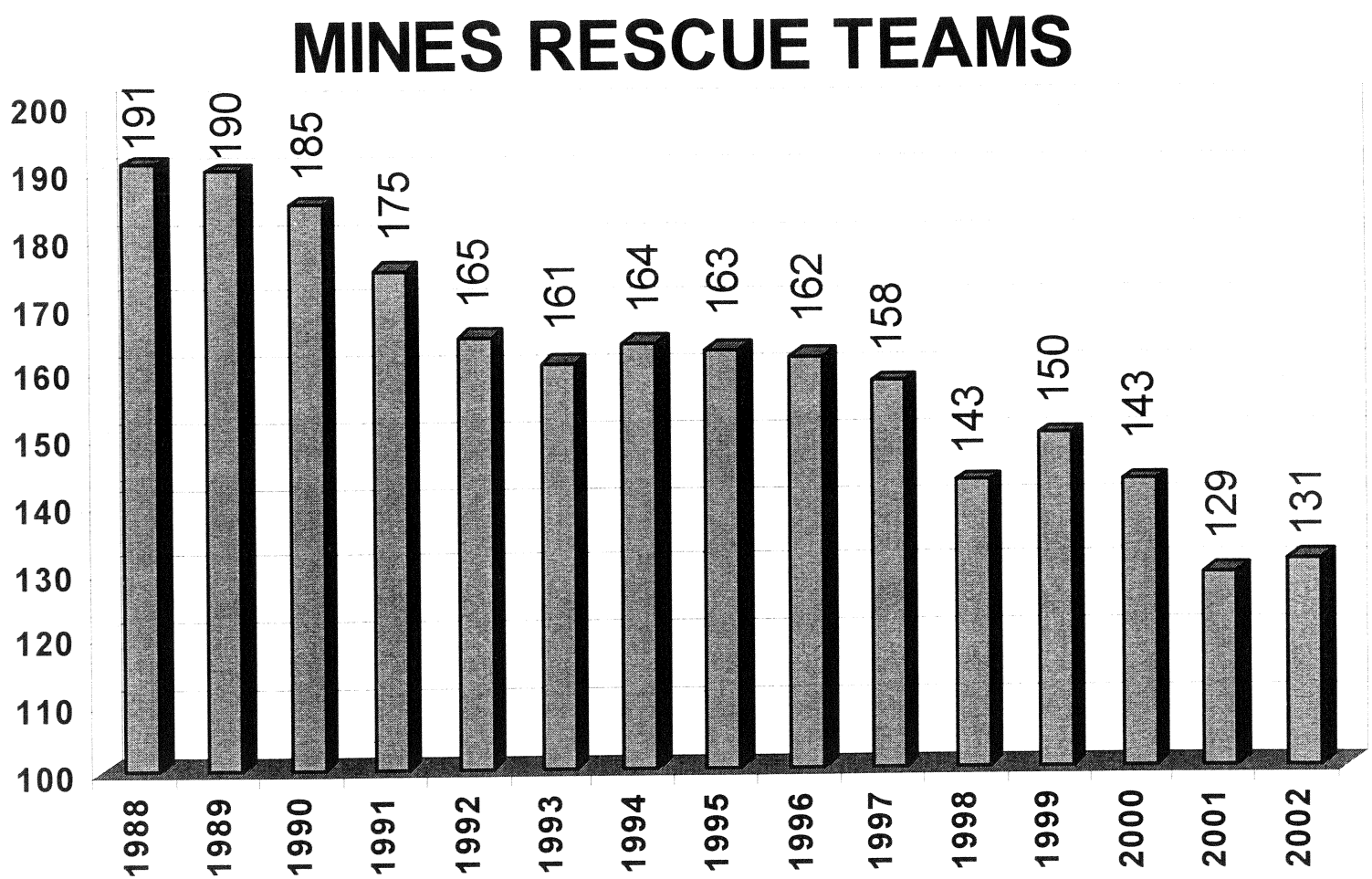
RESCUE BRIGADE STRENGTH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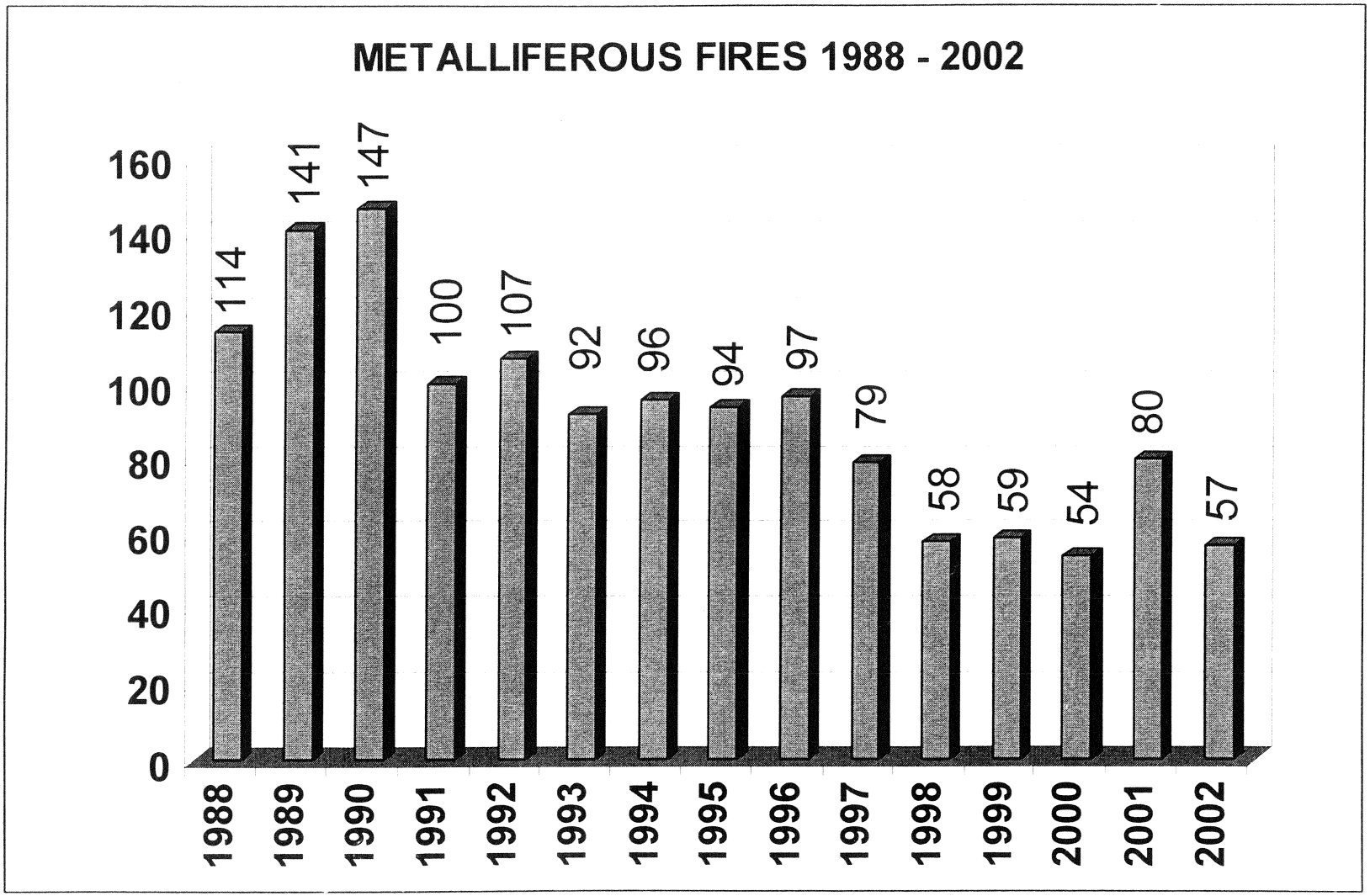
METALLIFEROUS FIRES 1988 - 2002
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TABLE 3

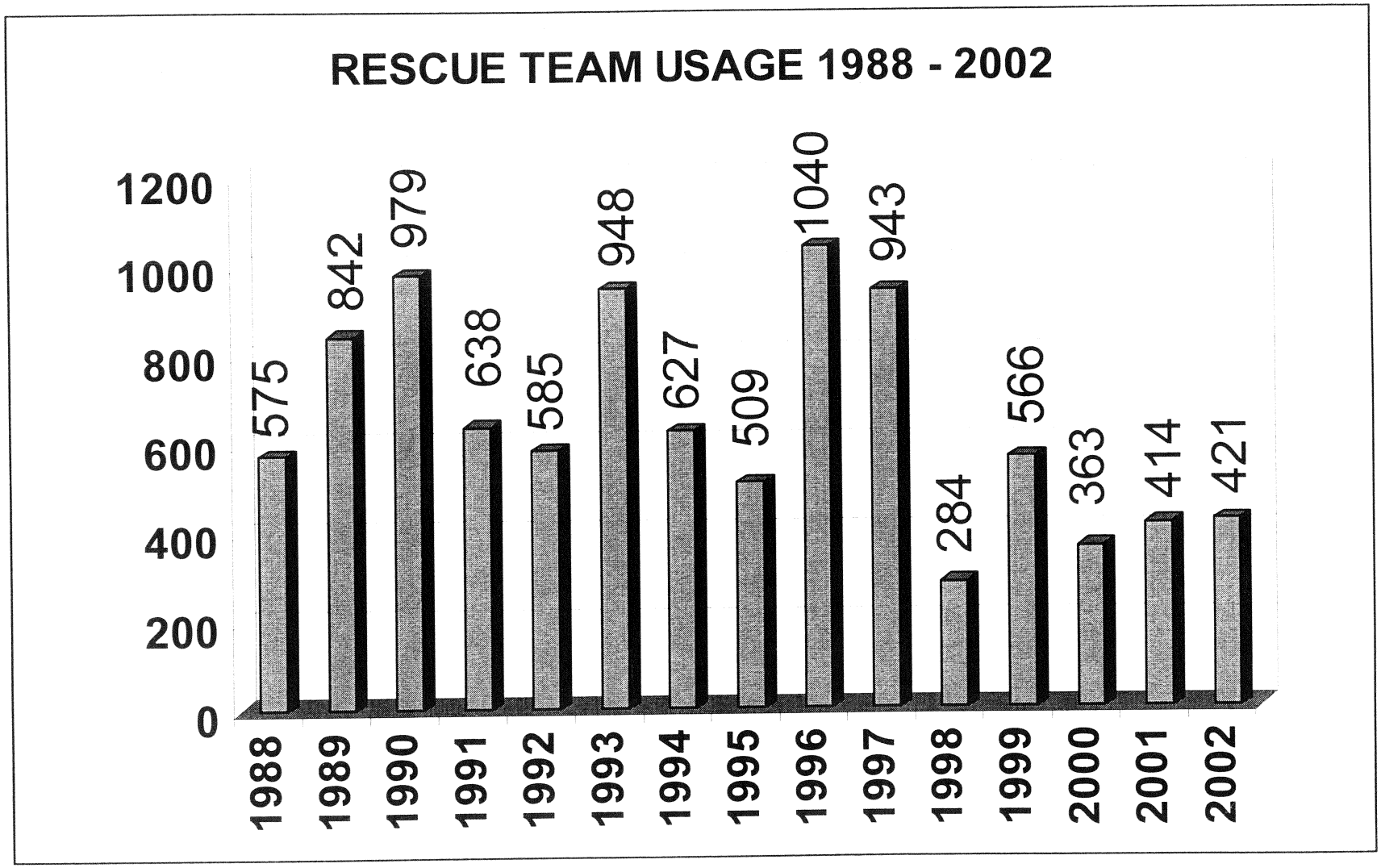
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TABLE 4