Report of investigation into the explosion of the diving cylinder on board local cruiser (24949) at Sai Kung Shelter anchorage on 18 October 2013.

Marine Accident Investigation Section
Marine Department
The Hong Kong Special Administrative Region

16 May 2017

Purpose of Investigation

The purpose of this investigation conducted by the Marine Accident Investigation and Shipping Security Policy Branch (MAISSPB) of Marine Department is to determine the circumstances and the causes of the incident with the aim of improving the safety of life at sea and avoiding similar incident in future.

We are not intended to apportion blame or liability towards any particular organization or individual except so far as necessary to achieve the said purpose.

The MAISSPB has no involvement in any prosecution or disciplinary action that may be taken by the Marine Department resulting from this incident.

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1. Description of the Vessel

1.1 Particulars of Cruiser (24949) "The vessel"

Certificate of Ownership Number	:	24949
Certificate Issuing Authority	:	Hong Kong Marine Department
Type of Ship	:	Class IV, Cruiser
Date of first licenced	:	15/04/1987
Length Overall	:	14.8 meters
Extreme Breadth	:	4.88 meters
Gross Tonnage	:	40
Net Tonnage	:	20
Material of Hull	:	Wood
No. of Person Permitted to Carry	:	32

Figure 1: Cruiser (24949)

1.2 Cruiser (24949), was a wooden vessel for pleasure purpose. She had one inboard propulsion engine (80.57kW). The *Vessel* was owned by the coxswain.

2. Sources of Evidence

2.1 The statement of the coxswain of cruiser (24949)

2.2 The government chemist report

2.3 Information provided by Harbor Patrol Section

3. Outline of Events

3.1. On 18 October 2013, the *Vessel* was anchored at Sai Kung Shelter Anchorage of Hong Kong. At about 1100 to 1200, the coxswain who was the owner of the *Vessel* boarded the *Vessel* to prepare for diving activities for the passengers in coming days.

3.2. The coxswain arranged to fill up the diving air cylinders on board alone by himself on the day. When the coxswain was filling up one of his aluminum diving cylinders, the cylinder exploded before the compressed air pressure inside could reach its normal working pressure of 180 bar. The explosion was so violent that he fainted and lost his conscious immediately. The coxswain recalled that he could not hear any explosion sound during the incident. After waking up, he made his way up to the forward of the weather deck.

3.3. The people on another ship passing by the *Vessel* noticed that the coxswain was bleeding and they phoned the police. The coxswain reached shore with their assistance and was then sent to Queen Elizabeth Hospital by an ambulance for intensive care. He was hospitalized for more than a month.

3.4. On 19 October 2013, the Marine Police, Fire Services Department officers and the government chemist boarded the *Vessel* for investigation. The Fire Services Department officers found that the *Vessel* had no immediate danger or potential risk. However, it was suggested to move the *Vessel* away from the Sai Kung Shelter Anchorage as the diving air cylinders were on board.

4. Analysis of Evidence

4.1. The *Vessel* was equipped with air compressors

a) On the *Vessel*, two air charging systems were fitted for charging the diving air cylinders. One of the air charging systems was driven by an electric motor and the other one was driven by a diesel engine.

b) One major criteria for the air compressor to produce quality compressed air into the diving cylinders was that the air compressor should not be situated against a wall in an inadequately ventilated small room on board. As this might result in producing compressed air with high level of carbon monoxide or moistures into the cylinders causing internal corrosion. From the picture (Figure 2) taken from the scene, it appeared that, the environment was not suitable to produce good quality of compressed air.

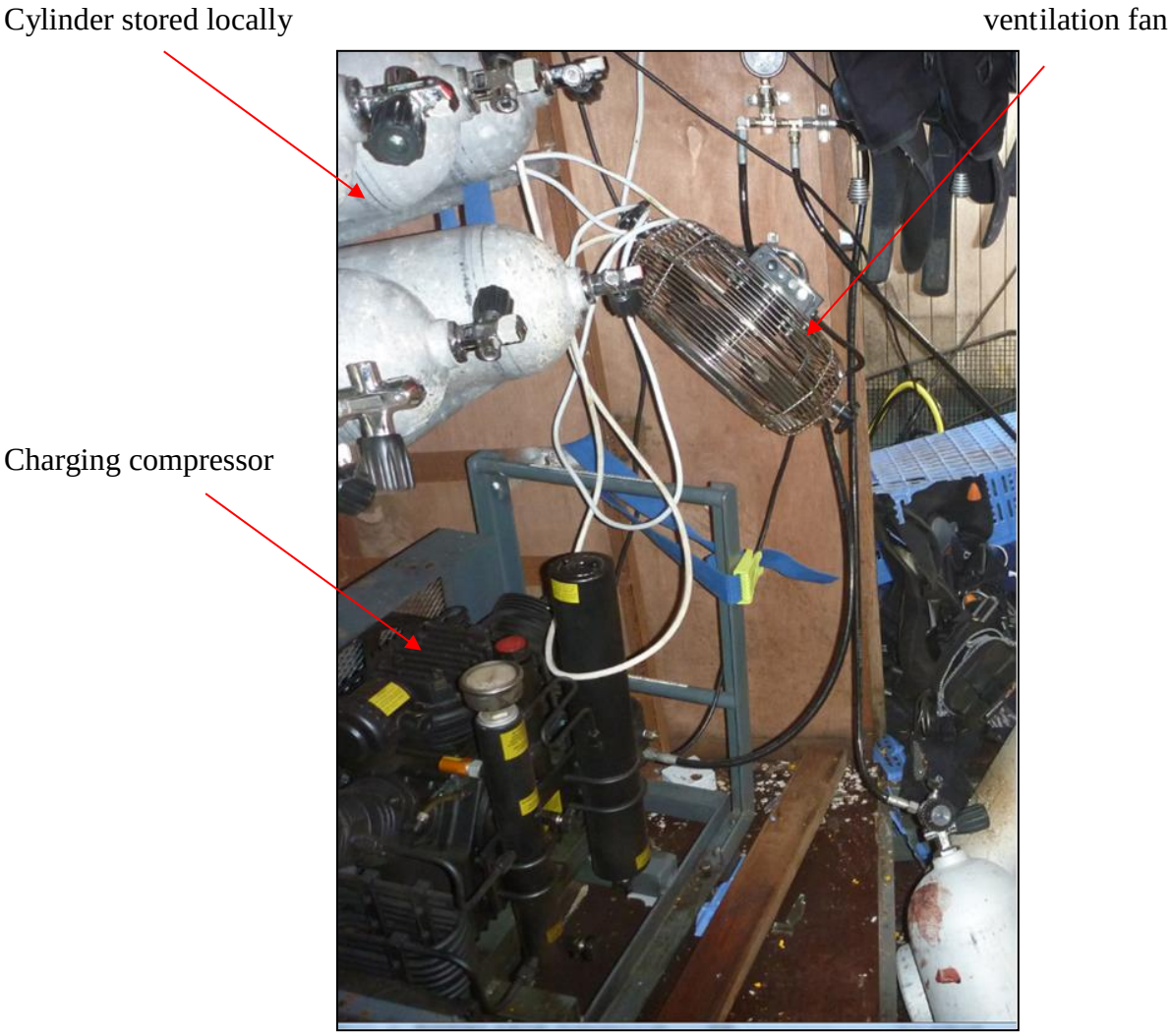

Figure 2: Air Compressor in the cylinder storage space

4.2. The *Vessel* stored unapproved air cylinders

c) In accordance with Regulation 3 "Classification of dangerous good" of CAP.295A "Dangerous Goods (Application and Exemption) Regulations," compressed air was categorized as category 2 class 1 dangerous goods.

d) In the incident, the coxswain was charged by Fire Services Department with storing and possessing air cylinders from land to sea that had not been approved by the department in accordance with Regulation 64 "Cylinders to be approved by the Authority" of CAP.295B "Dangerous Goods (General) Regulations".

e) A proper cylinder storage space was also important. The space should be clean and dry to avoid corrosion to the cylinders.

4.3. Configuration of the Compressed Air Charging System

f) The Government Chemist Report (dated 19 November 2013) confirmed that the content stored inside the diving cylinders were compressed air.

g) There were two same air charging systems and 68 diving air cylinders onboard. One air charging system was driven by an electric motor and the other one was driven by a diesel engine

h) Each of the 2 air charging systems contained a reciprocating piston type air compressor with the following particular:

- Maker : Aerotecnica Coltri
- Model : MCH-16
- Filling time cylinder 10L, 0-200 bar : 9 min

i) While the charging was taking place, each of the systems (Figure 3) was composed of the components with specifications as followings:

- A 3-stage air compressor (Aerotecnica Coltri) with inter-coolers (air) after each stages of compression;
- An air purifier;
- A pressure gauge (0-400 bar);
- Flexible charging hoses with clamping valves;
- Diving air cylinders and the cylinder valve with a build-in bursting disc.
- Each system was capable of filling up 2 cylinders simultaneous.

- Safety devices in the system for high pressure:
  - There was an over-pressure safety valve at the outlet of the final stage of compression, the safety valve was installed on the air receiver.
  - There was a bursting disc installed in each cylinder valve.

j) The control system was in manual mode only. There was no pressure switch fitted. The filling systems were not able to stop the air compressors when reaching the required pressure.

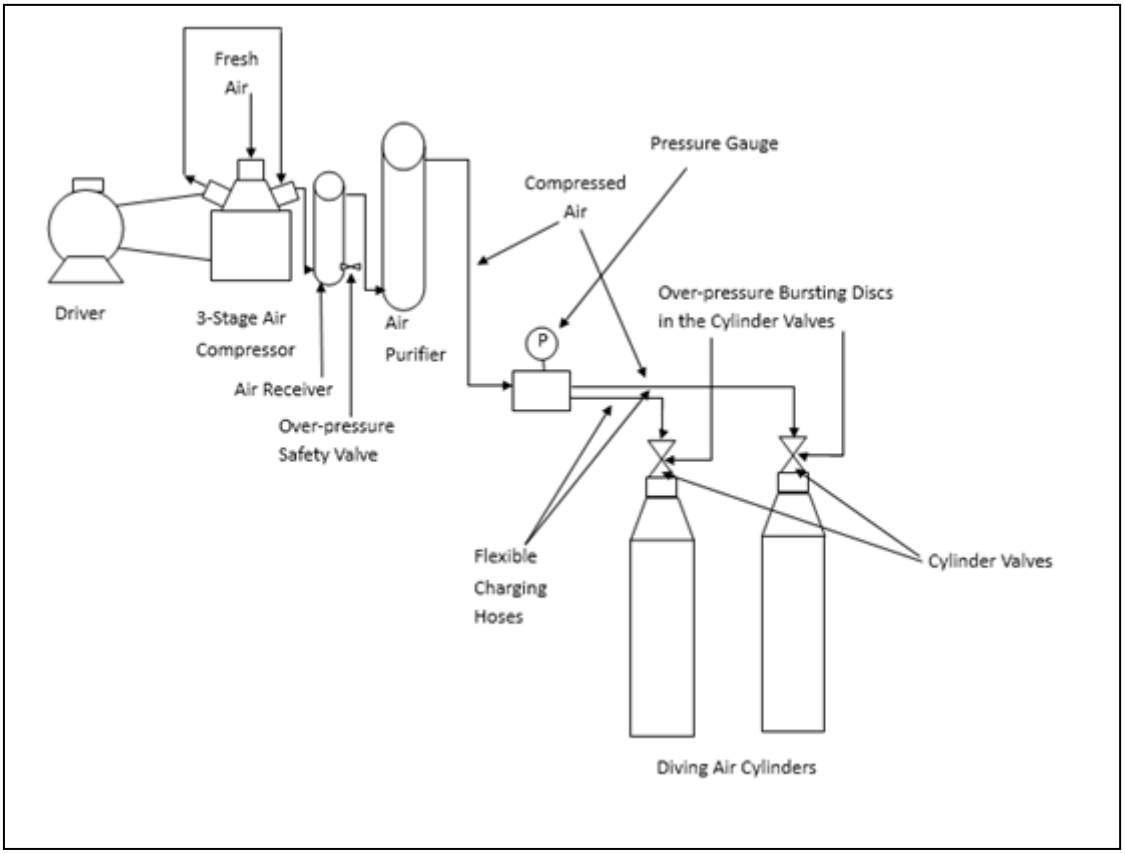

Figure 3: Configuration of the air charging system

4.4. Air cylinders examination and testing

k) The diving air cylinders needed to be checked on a regular basis as per the manufacturer's recommendations. This involved both the internal and external inspection and a hydrostatic test. Hong Kong Underwater Association recommended the diving air cylinder to be internally inspected including the cylinder valves function test at intervals not exceeding twelve months. The diving air cylinders should be hydrostatically tested as per the manufacturer's recommendations or the relevant local standards. In the United States and some European Countries, the interval for the hydrostatic test was 5 years.

l) As the coxswain stated that the inspection and testing to the exploded cylinder was done by shore service about a year before the incident in 2012, the mark on a similar cylinder

indicated the date of inspection was October 2012.

4.5. **The coxswain did not carry out cylinder inspection properly before filling the cylinder**

m) Before the filling-up, it was important to examine the cylinder externally for any defects such as sign of wear-down, deformation, and the condition of the burst disc.

n) The coxswain failed to carry out this inspection properly before filling the defective cylinder with compressed air. The picture below (Figure 4) shows one of the defective cylinders which was not charged yet with corroded external shell lying on the floor.

Figure 4: Corroded air cylinder

4.6. The details of the exploded diving cylinder

o) The coxswain reported that the compressed air pressure of the exploded diving cylinder was still far below the normal working pressure (180 bar) at the time of the explosion.

p) The exploded cylinder was made of aluminum. Corrosion rate of aluminum by water was largely dependent on the composition of the water. In sea water with heavy metals, the durability of the aluminum cylinder would be reduced greatly.

q) Aluminum was subjected to stress cracking. Corrosion accelerated by the high pressure of the air in the cylinder led to critical weakening of the cylinder shell. The exploded cylinder was inspected in October 2012 with stamping on the cylinder.

r) The fragment of the exploded cylinder shell indicated the following defects (Figure 5):

- General internal and external corrosion;
- localized internal pitting; and
- stress corrosion cracking formed through the simultaneous action of applied stresses and a corrosive environment.

s) The above defects on the cylinder reduced the material strength, and led to large flaws that eventually resulted in structural failure. The cylinder exploded below the normal working pressure.

Figure 5: Internal surface of the exploded cylinder was corroded with pitting holes

5. Conclusions

5.1. On 18 October 2013, when an unnamed Hong Kong local cruiser with local operating license no. 24949 anchored at "Sai Kung Shelter Area", the coxswain boarded the *Vessel* alone and tried to charge up the diving air cylinders stored on board.

5.2. When the coxswain was charging up one of aluminum diving cylinders, the cylinder exploded unexpectedly before reaching the normal working pressure of 180 bar. The explosion was so violent that he fainted immediately. After waking up, he made his way up to the forward of the weather deck to call for help from another ship nearby. The coxswain was then sent to Queen Elizabeth Hospital for intensive care. He was hospitalized for more than a month.

5.3. The following were the possible contributory factors leading to the explosion:

- The coxswain did not properly inspect the cylinder for any external defects before the filling-up.
- The exploded cylinder was corroded internally and externally.
- The exploded cylinder was made of aluminum which was subjected to stress cracking. Corrosion was accelerated by the high air pressure inside the cylinder that led to weakening of the cylinder shell.
- The general corrosion and scattered pitting holes on the cylinder shell reduced the material toughness, and led to large flaws that eventually resulted in structural failure.

6. Recommendations

6.1. A copy of this report should be sent to the coxswain, advising him the findings of this incident.

6.2. Only the approved diving air cylinders that were properly maintained and tested according to manufacturer's instructions should be carried on board.

6.3. A copy of this report should be sent to the Dangerous Goods and Prosecution Section of Marine Department, Fire Services Department and the Boilers & Pressure Vessels Division of Labour Department, advising them the findings of this incident.

7. Submissions

7.1 The draft report was forwarded to the coxswain of the cruiser, the Dangerous Goods and Prosecution Section of Marine Department, Fire Services Department and the Boilers & Pressure Vessels Division of Labour Department for comment.

7.2 During the consultation period, comments from the Fire Services Department were received and had been considered. The report has been amended accordingly.