CCO Ltd

Diving management studies
Study No 8

Set a policy for electronic devices in chambers

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Important Note

This study is written with the only aim of informing people interested in diving activities of the elements to take into account to prepare successful operations. However, the implementation of the procedures discussed is the sole responsibility of the reader.

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1 - Purpose

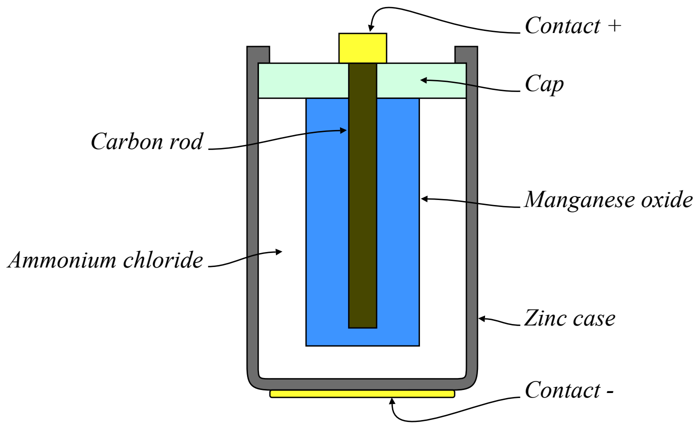
The electronic and computing industries propose products that are increasingly reliable, compact, and easy to implement, in addition, to the fact that they provide much more functions than the electromechanical devices they are gradually replacing for all these reasons. Thus, we can say that digital electronic apparatuses have become an essential part of our universe as we are today fully dependent on them.
An aspect of this dependence is that most people working in the offshore industry consider cell phones, tablets, laptops, and video games essential means of contact and entertainment they do not want to be deprived of. As a result, these devices are omnipresent in the accommodations and consequently in the hyperbaric chambers.
However, the use of electrical and electronic apparatus in hyperbaric chambers poses several safety problems. The most discussed is that their batteries are often involved in undesirable events such as thermal runaways resulting in sudden fires. For these reasons, rules must be implemented regarding the transfer and use of such systems in chambers. These directives must be risk assessed to ensure that any hazard is considered and relevant control measures are in place. This process is to be done by the company management and, of course, the divers as they are the most involved in case of an incident. The purpose of this study is to provide elements for the elaboration of guidelines.

2 - Batteries that can be found in chambers

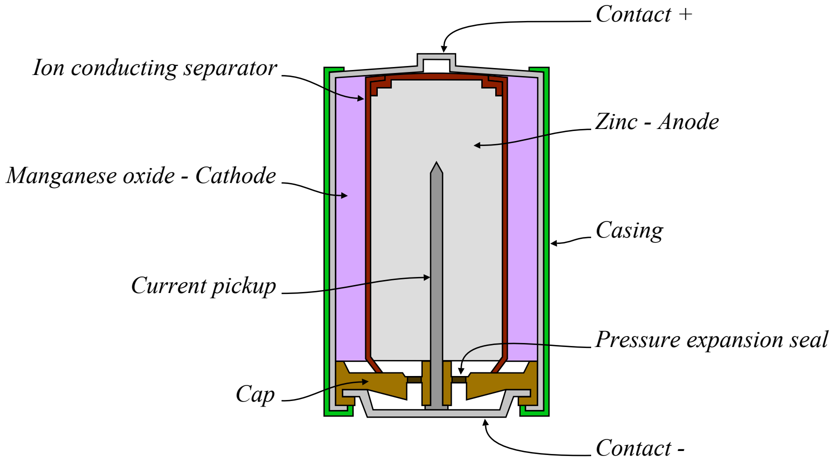
The batteries that can be used to energize portable items usually found in chambers, can be classified as follows:

2.1 - Non-rechargeable batteries

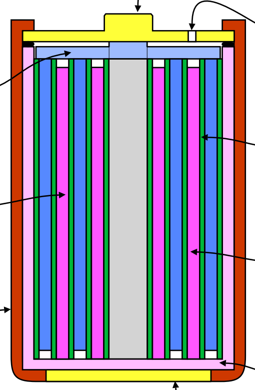
- zinc–carbon batteries:
  Zinc-carbon batteries are composed of a zinc can (anode) that contains a layer of ammonium chloride ($NH4Cl$) or zinc chloride ($ZnCl$ 2), impregnating a paper layer that separates the zinc can from a mixture of powdered carbon (graphite) and manganese oxide ($MnO2$), which is packed around a carbon rod. These batteries are the 1st model commercialised, and are reputed very safe. However, they offer a limited capacity compared with more recent systems. Despite this inconvenience these batteries are still used to energize small items such as portable lights, remote commands, portable analysers, etc.. One of the reasons they are still fabricated is that they are cheap. Another inconvenience of these batteries is that their chemical components leak outside the container when they are at the end of their life, which may result in corrosion or destruction of the contacts of the items they energise.



- Alkaline batteries
  These batteries are composed of an alkaline electrolyte of potassium hydroxide (KOH), a negative electrode made of zinc, and a positive electrode made of manganese dioxide (MnO_2). The alkaline electrolyte, made of potassium hydroxide, is not part of the reaction; only zinc and manganese dioxide are consumed during discharge. These batteries are used for the same applications as zinc-carbon batteries. However, an alkaline battery has between three and five times the capacity of a zinc-carbon battery.

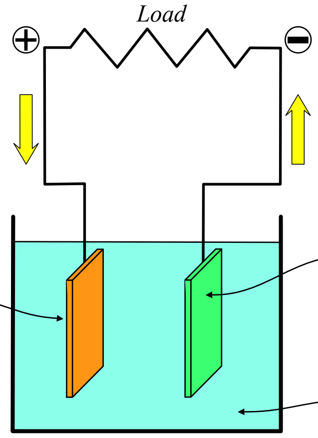


- Primary lithium batteries /lithium-metal batteries
  Disposable primary lithium batteries, also referred to as lithium-metal batteries, must be distinguished from secondary lithium-ion or lithium-polymer, which are rechargeable batteries.
  These batteries have metallic lithium as an anode. The most common type uses metallic lithium as the anode and manganese dioxide as the cathode, with a salt of lithium dissolved in an organic solvent as the electrolyte.
  These batteries provide high charge density and voltages from 1.5 V to approximately 3.7 V. They are much more durable than alkaline batteries, and can be used for the same applications. They are also the preferred batteries to energize items such as watches, clocks, cameras, calculators, computer BIOS, gas analysers, pacemakers, and other medical and scientific equipment.
  Note that such batteries have been involved in numerous incidents. For this reason, limitations regarding their transportation have been enforced.



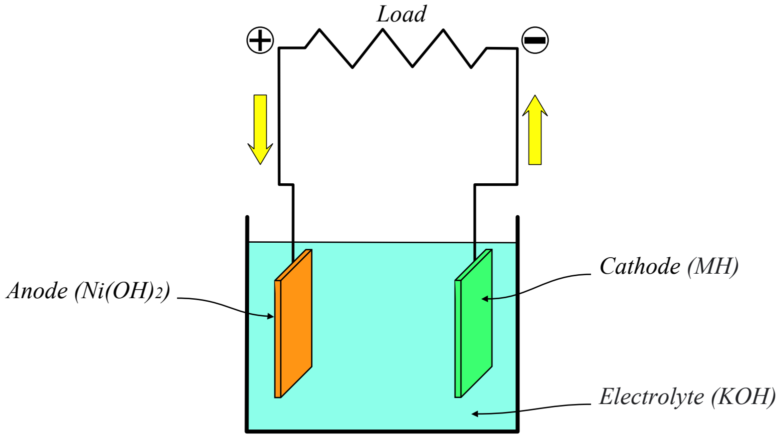
2.2 - Rechargeable batteries

- Nickel-cadmium batteries
  Nickel-cadmium batteries use nickel oxide hydroxide and metallic cadmium as electrodes. Typically, the positive electrode is made of Nickel hydroxide (Ni(OH)2), and the negative electrode is composed of Cadmium hydroxide (Cd (OH) 2), with the electrolyte itself being Potassium hydroxide (KOH). They are commonly developing 1.2 volts when used individually. Miniature units can be used for energizing cameras, computer-memory standby, gas detectors, and other devices. They can also be assembled into battery packs (power banks) that develop higher voltages and can be used to refill cell phones and other devices. The advantages of these batteries are that they can be stored for a long time, either discharged or charged.
  The main inconveniences of such batteries are their relatively low energy density and low charge capacity. Also, they have a limited number of charging and discharges cycles (about 1000 cycles). In addition, they start to lose their voltage after a certain number of cycles or repeated incomplete charges and discharges. This voltage depression is called the “memory effect”.
  Note that the electrolyte of these batteries is corrosive. As a result, contact with internal components may irritate the eyes, respiratory system, and skin. Improper charging can cause heat damage or even high-pressure rupture. Also, should an individual cell from a battery become disassembled, spontaneous combustion of the negative electrode is possible.

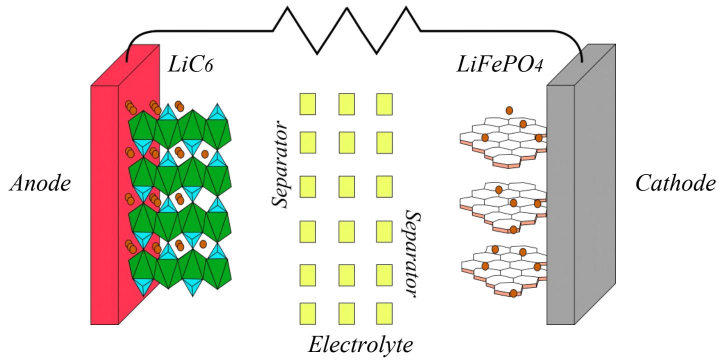


- Nickel metal hydride batteries
  Nickel metal hydride batteries have a chemical reaction at the positive electrode similar to that of the nickel-cadmium cell with the Anode made of nickel hydroxide (Ni(OH)2) and the electrolyte composed of potassium hydroxide (KOH). However, the Cathode is made of hydrogen-absorbing alloys (MH).
  These batteries have two to three times the capacity of nickel-cadmium batteries of the same size, with significantly higher energy density, although much less than lithium-ion batteries. They are used for similar applications to Nickel-cadmium batteries and replace traditional acid batteries and energize hybrid and electrical

cars, despite lithium-ion batteries being preferred for such applications.
These batteries are usually hermetically sealed. However, the electrolyte is composed of hazardous material that can cause severe irritation and chemical burns if released. Also, a harmful fume is emitted in case of a fire. Nevertheless, prevention of fire and explosion is said not to be necessary under normal use.



- Lithium-ion batteries
  Among the various existing energy storage technologies, rechargeable lithium-ion batteries are considered an effective solution to the increasing need for high-energy electro-chemical power sources.
  Rechargeable lithium-ion batteries offer energy densities 2 - 3 times and power densities 5 - 6 times higher than conventional nickel-cadmium and nickel-metal hydride batteries. Thus, they weigh less, take less space, and deliver more energy. In addition, these batteries have low self-discharge, high operating voltage, and no "memory effect."
  Each lithium-ion battery consists of an anode and a cathode separated by an electrolyte containing dissociated lithium salts, which enables the transfer of lithium ions between the two electrodes, as illustrated below:



  The electrolyte containing dissociated lithium salts, which enables the transfer of lithium ions between the two electrodes, is typically contained in a porous separator membrane that prevents the physical contact between the anode and cathode.
  When the battery is being charged, an external electrical power source injects electrons into the anode, composed of Lithium atoms intercalated between graphite sheets ($LiC6$). At the same time, the cathode, composed of lithium iron phosphate ($LiFePO_4$), gives up some of its lithium ions, which move through the electrolyte to the anode and remain there. During this process, electricity is stored in the battery in the form of chemical energy.
  When the battery discharges, the lithium ions move back across the electrolyte to the cathode, enabling the release of electrons to the outer circuit to do the electrical work.
  Lithium-ion batteries were mainly developed for portable devices such as cell phones, portable games, laptops, etc. They are also gradually designed for electric cars and the aviation industry. These batteries cumulate all advantages compared to the other models. However, they are also those the most involved in incidents such as unexpected fires. For this reason, their transportation is subject to stringent limitations.

3 - The certification process of batteries and electronic apparatus

Batteries cannot be sold without being certified as safe for the usage they are designed for. Regarding this matter, the high energy density of the lithium-ion batteries coupled with their flammable components creates new challenges regarding their storage and handling compared to the classical batteries using aqueous electrolytes that are considered more stable. As a result, and following incidents, the tests of Lithium-ion (Li-ion) batteries have been reinforced.
These tests are performed according to standards emitted by certification bodies that are internationally recognized and approved by the states where the batteries are sold, such as those listed below, but not limited to:

- UL, also known as Underwriters Laboratories, is a certification company involved in various industries, financial services, and governmental support, which operates worldwide and is headquartered in Northbrook in the USA.
- The International Electro-technical Commission (IEC) is an international standards organization involved in

electrical, electronic and related technologies that is headquartered in Geneva Switzerland.

- The Institute of Electrical and Electronics Engineers (IEEE) is an American non profit organization for electronic and electrical engineering with headquarters in New York.
- The United Nations "Manual of tests and Criteria" sets up procedures to be used for the classification of dangerous goods. The test requirements regarding batteries can be found in Part III/Subsection 38.3 (page 420).

The table below summarizes some tests and recommendations promoted by the organizations listed above.

Test purpose	***Description***	***Standards***
Insulation and Wiring	Minimum electrical resistance requirements for positive terminal and internal wiring insulation for batteries.	IEC 62133: 2.1
Maximum voltage Protection	The cell is subjected to the maximum voltage allowed by protection electronics; cell is insulated to create adiabatic conditions for 24 hours	IEEE 1725 6.14.5.1
Abnormal charging test	Over-current charging test (constant voltage, current limited to 3X specified max charging current); testing at 20°C (68°F); testing of fresh and cycled ("conditioned") cells; seven hours duration.	UL 1642, Sec 11 UL 2054, Sec 10 IEC 62133: 4.3.11
Overcharge	A discharged cell is charged by a power supply at a minimum of 10 V for an extended period.	IEC 62133: 4.3.9
	When the manufacturer's recommended charge voltage is not more than 18 V, the minimum voltage of the test is two times the maximum charge voltage of the battery or 22 V. When the manufacturer's recommended charge voltage is more than 18 V, the minimum voltage of the test is 1.2 times the maximum charge voltage.	UN - Manual of tests & criteria - Part III/38.3
Continuous low-rate charging	Fully charged cells subjected to manufacturer specified charging for 28 days, testing at 20°C (68°F); testing of fresh cells.	IEC 62133: 4.2.1
Forced discharge test	For multi-cell applications only; over-discharge test; testing at 20°C (68°F); testing of fresh and cycled cells.	UL 1642, Sec 12 UL 2054, Sec 12 IEC 62133: 4.3.10
	Each cell is forced discharged at ambient temperature by connecting it in series with a 12V D.C. power supply at an initial current equal to the maximum discharge current specified by the manufacturer.	UN - Manual of tests & criteria - Part III/38.3
Short-circuit test	Short circuit the cell through a maximum resistance of 0.1 ohm; testing at 20°C (68°F) and 55°C (131°F); testing of fresh and cycled cells.	UL 1642, Sec 10 UL 2054, Sec 9 IEC 62133: 4.3.2
	Short circuit the cell through a maximum resistance of 0.05 ohm; testing at 55°C (131°F); testing of fresh cells.	IEEE 1725 5.6.7
	The cell or battery to be tested is heated for a period of time necessary to reach a homogeneous stabilized temperature of 57 ± 4 °C, measured on the external case. This period of time depends on the size and design of the cell or battery and should be assessed and documented. If this assessment is not feasible, the exposure time shall be at least 6 hours for small cells and small batteries, and 12 hours for large cells and large batteries. Then the cell or battery at 57 ± 4 °C is subjected to one short circuit condition with a total external resistance of less than 0.1 ohm. This short circuit condition is continued for at least one hour after the cell or battery external case temperature has returned to 57 ± 4 °C, or in the case of the large batteries, has decreased by half of the maximum temperature increase observed during the test.	UN - Manual of tests & criteria - Part III/38.3
Evaluation of excess lithium plating	A production lot of cells is cycled 25 times at maximum charge/discharge rate specified by the manufacturer at 25°C (77°F). Minimum five cells then to be subjected to UL external short circuit test at 55°C (131°F). A minimum of five cells are examined for evidence of lithium plating.	IEEE 1725 5.6.6
Temperature cycling test	Test cells and batteries are stored for at least six hours at a test temperature equal to 72 ± 2 °C, followed by storage for at least six hours at a test temperature equal to - 40 ± 2 °C. The maximum time interval between test temperature extremes is 30 minutes. This procedure is to be repeated until 10 total cycles are complete, after which all test cells and batteries are to be stored for 24 hours at ambient temperature (20 ± 5 °C). For large cells and batteries the duration of exposure to the test temperature extremes should be at least 12 hours.	UN - Manual of tests & criteria - Part III/38.3
	The cell is cycled between high and low temperatures: four hours at 75°C (167°F), two hours at 20°C (68°F), four hours at - 20°C (-4°F), return to 20°C, and repeat the cycle a further four times; testing of fresh cells.	IEC 62133: 4.2.4

Test purpose	***Description***	***Standards***
Temperature cycling test	The cell is cycled between high- and low-temperatures: four hours at 70°C (158°F), two hours at 20°C (68°F), four hours at -40°C (-40°F), return to 20°C, and repeat the cycle a further nine times; testing of fresh and cycled cells	UL 1642, Sec 18 UL 2054, Sec 24
Heating test	Cell or battery placed into an oven initially at 20°C (68°F); oven temperature is raised at a rate of 5°C/minute (9°F/min) to a temperature of 130°C (266°F); the oven is held at 130°C for 10 minutes, then the cell is returned to room temperature; testing of fresh and cycled cells.	UL 1642, Sec 17 UL 2054, Sec 23 IEC 62133: 4.3.5
	Cell or battery placed into an oven initially at 20°C (68°F); oven temperature is raised at a rate of 5°C/minute (9°F/min) to a temperature of 130°C (266°F); the oven is held at 130°C for 1 hour, then the cell is returned to room temperature; testing of fresh and cycled cells.	IEEE 1725 5.6.5 and 1625 5.6.6.
Moulded case stress at high ambient temperature	The battery is placed into an air-circulating oven at 70°C (158°F) for seven hours; testing of fresh batteries	IEC 62133: 4.2.3
Altitude simulation	The cell is stored for six hours at 11.6 kPa (1.68 psi); testing at 20°C (68°F); testing of fresh and cycled cells.	UL 1642, Sec 19 IEC 62133: 4.3.7 UN - Manual of tests & criteria - Part III/38.3
Crush test	The cell is crushed between two flat plates to an applied force of 13 kN (3,000 lbs); testing of fresh and cycled cells.	UL 1642, Sec 13 UL 2054, Sec 14 IEC 62133: 4.3.6
Shock test	Three shocks applied with minimum average acceleration of 75 g; peak acceleration between 125 and 175 g; shocks applied to each perpendicular axis of symmetry; testing at 20°C (68°F); testing of fresh and cycled cells.	UL 1642, Sec 15 UL 2054, Sec 16 IEC 62133: 4.3.4
	Test cells and batteries are secured to the testing machine by means of a rigid mount which support all mounting surfaces of each test battery. Each cell is subjected to a half-sine shock of peak acceleration of 150 gn and pulse duration of 6 milliseconds. Alternatively, large cells may be subjected to a half-sine shock of peak acceleration of 50 gn and pulse duration of 11 milliseconds. Each battery is subjected to a half-sine shock of peak acceleration depending on the mass of the battery. The pulse duration is 6 milliseconds for small batteries and 11 milliseconds for large batteries.	UN - Manual of tests & criteria - Part III/38.3
Impact test	A 15.8 mm to 16 mm diameter bar is placed across a cell; a 9.1 kg (20 lb) weight is dropped on to the bar from a height of 24 inches (61 cm); testing at 20°C (68°F); testing of fresh cells.	UL 1642, Sec 14 UL 2054, Sec 15
	The test sample cell or component cell is placed on a flat smooth surface. A 15.8 mm ± 0.1 mm diameter, at least 6 cm long, or the longest dimension of the cell, whichever is greater. A type 316 stainless steel bar is placed across the centre of the sample. A 9.1 kg ± 0.1kg mass is dropped from a height of 61 ± 2.5 cm at the intersection of the bar and sample in a controlled manner using a near frictionless, vertical sliding track or channel with minimal drag on the falling mass. The vertical track or channel used to guide the falling mass is oriented 90 degrees from the horizontal supporting surface. The test sample is impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8 mm ± 0.1 mm diameter curved surface lying across the centre of the test sample. Each sample is to be subjected to only a single impact.	UN - Manual of tests & criteria - Part III/38.3
Pack drop test	A package filled with cells or battery packs is dropped from a height of 1.2 m onto a concrete surface such that one of its corners hits the ground first	IEC 62281: 6.6.1
	Fully charged packs dropped from a height of 1.5 m onto smooth concrete for up to six repetitions on six sides (36 times); open circuit voltage monitored for evidence of internal shorts.	IEEE 1725.6.14.6
Free Fall	Each cell or battery is dropped three times from a height of 1 m onto a concrete floor	IEC 62133 4.3.3
Vibration test	Simple harmonic vibration applied to cells in three perpendicular directions; frequency is varied between 10 and 55 Hz; testing at 20°C (68°F); testing of fresh cells.	UL 1642, Sec 16 UL 2054, Sec 17 IEC 62133: 4.2.2

Test purpose	Description	Standards
Vibration test	Cells and batteries are firmly secured to the platform of the vibration machine without distorting the cells in such a manner as to faithfully transmit the vibration. The vibration is a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 minutes. This cycle is repeated 12 times for a total of 3 hours for each of three mutually perpendicular mounting positions of the cell. One of the directions of vibration must be perpendicular to the terminal face.	UN - Manual of tests & criteria - Part III/38.3
Venting	Requirement for a pressure relief mechanism on cells	IEC 62133: 2.2

Cell phones, laptops, and other portable electronic apparatuses are submitted to similar tests to the batteries that energize them. These tests are described by the competent bodies indicated above or organizations such as the Joint Electron Device Engineering Council (JEDEC), which develops open standards for the global microelectronics industry, with over 300 member companies. This organization, which has published over 382 standards, is accredited by the American National Standards Institute (ANSI), and maintains liaisons with numerous standards bodies throughout the world. It is headquartered in Arlington, Virginia, USA.

Among the numerous tests applied to electronic devices, those related to the ability of portable equipment to withstand shocks have become essential. The reason is that, according to reports from transportation industries, consumer associations, and manufacturers, a lot of fire scenarios of laptops and cell phones have been provoked by shocks, such as a device dropping to the floor or unintentionally hit during a manipulation. Specialists explain that when an electronic apparatus is accidentally dropped or is hit, impact forces are transmitted from the devices' case to the printed circuit board and other components within the case, which may cause component failure and interconnection breakage. Consequently, these failures may trigger a short circuit or an undesirable reaction of the chemical components of the battery.

Traditionally, the robustness of products is obtained through a design & failure process demonstrated through tests. As an example of the tests that can be applied, the “free fall drop test method” simulates users dropping their devices by accident where the device falls under the sole gravity. This is performed from a raised platform from which the apparatus is dropped with all possible angles. Note that the drop height can be varied according to the design requirements. It may also happen that the object to test is hand released to introduce a certain random level. Another well-known method is the “controlled pulse drop test”, where the acceleration and the impact force of the dropped object are controlled using a machine that hits it to a targeted surface in a controlled manner.

During the various experimentations to which the device is submitted, the damages accumulated in the components and their interconnections are logged and investigated. A damage estimation model is then used to assess the risks of failure and their consequences to determine its robustness and safety of use. Manufacturers and certification bodies use these data and those from other sources to decide whether the apparatus can be sold or corrective measures need to be implemented to reinforce it. Note that the norms under which the apparatus has been tested must be indicated on it.

Regarding this matter, it seems that no official test has been published regarding the capability of cell phones, laptops, and similar devices to withstand repeated exposures to hyperbaric conditions successfully. Note that the altitude simulation tests described for batteries are not sufficient as they are designed to control the ability of these objects to resist a depression instead of compression and that the maximum depression in the cargo of a plane is limited to less than 1 bar (787 mb) at 11,000 m altitude when the absolute pressure at 300 msw is 31 bar. Thus, we can say that the divers have improvised the pressure tests of the electronic devices they have transferred in chambers.

4 - Guidelines provided by the diving industry

Two organizations have published guidelines regarding using devices powered by batteries in hyperbaric chambers that can be taken into consideration:

- The well-known International Marine Contractor Association (IMCA), which is described in book #1 of this manual, and defends the interest of its members, has published the diving guidance IMCA D 041 “Use of battery-operated equipment in hyperbaric conditions”.
- QinetiQ, a multinational defense technology company, headquartered in Farnborough in England, has published a recommendation report called “A risk-based investigative study into the safety implications of using lithium-ion batteries in hyperbaric treatment chambers & saturation diving compression chambers”.

4.1 - IMCA D 041 “Use of battery-operated equipment in hyperbaric conditions” (October 2006)

This document updates and replaces the guidance AODC 62 “Use of battery-operated equipment in hyperbaric conditions”, published in 1993.

The authors of this document highlight the following risks and control measures:

- Items developing internal voltages over 30 volts DC can potentially be sources of electric shocks. However, the document's authors recognize that the battery-powered devices considered in this note use voltages significantly below the limit from which electric shocks are possible.
- The risks linked to battery-operated equipment in hyperbaric conditions are mostly overheating, fire, and leakage of toxic material, caused by partial or complete electrical short-circuits developing across the batteries. However, the authors of this document say that a mechanical accident is necessary to create such undesirable events from these low-energy devices. Also, even though it is theoretically possible that the ignition of the

materials that compose the device can then propagate in an oxygen-enhanced atmosphere, this combination of circumstances is improbable, and it can be minimized by limiting the power of the batteries.
The authors of this guidance conclude their analysis regarding fire risks by saying that measurements and trials would have to be carried out on each item and that if that is not possible, "any judgment on safety must be based upon the experience of the maximum size and type of battery that can be safely used under hyperbaric conditions to limit to a reasonably low level the energy available to cause serious overheating".

- There may be failure of the equipment during compression which may result in the collapse of the components or implosion in case of vacuum devices. The authors of the guideline suggest that such incident would not be a serious hazard to the chamber's occupant and the Life Support Technicians (LST).
- Helium may enter into the components during the saturation and cause the battery to explode during a rapid decompression in the medical lock. Also, it is said that another risk of explosion is linked to the possibility that the accumulated pressure in the battery may not be released sufficiently quickly during the ascent of the chamber. As control measures, the authors suggest that precaution must be in place when transferring such items through the medical lock with controlled and not too fast decompression and also ensuring that the devices transferred are designed to allow for equalization.
- Items, such as batteries, contain potentially toxic materials that can be released into the chamber atmosphere, causing pollution. The control measures suggested by the authors of the guidance are to limit the size of batteries to cells no larger than 'AA' size (1.5v) NiMH rechargeable or their physical equivalent in non-rechargeable form (500 mA/hr), and that items containing potentially toxic materials should not be permitted in chambers. In case of doubt about the composition of a battery, it should not be used until a competent person has assessed it. In addition, alternative solutions to batteries should be considered, and the authors of the document say that battery charging should never be performed in the chamber.
- It is also said that when some cells in a battery are exhausted, this places stress on the remaining cells, resulting in a reverse polarisation. For this reason, it is suggested that all batteries of a pack should be renewed at the same time. In addition, batteries can be affected by corrosion, and for this reason, they must be protected from humidity and immediately removed if the exposure to moisture has damaged them.

The document is completed by a table that classifies the battery-operated devices into those that are prohibited in a hyperbaric environment and those that can be used in such conditions following a relevant risk assessment. The authors of the document call this second category "potential problem".

- The prohibited devices are the following:
  - Rechargeable power tools
  - Batteries containing potentially toxic materials (mercury, lead-acid, lithium dioxide, lithium).
  - Mobile phones
  - Battery chargers
  - Cathode ray tube TV monitors
- The devices classified "potential problem" are the following:
  - LCD monitors/video players
  - Portable computers (laptops)
  - Rechargeable torches (not diver's type torch in a pressure housing)
  - iPod, Personal Digital Assistants (PDA)
  - Calculators
  - Cameras
  - Dictaphones
  - Digital analysers
  - Electronic clocks
  - Mini Disc players
  - Shavers
  - Toothbrushes

Note that this guidance has been published more than 15 years ago and should be updated:

- Portable computers and iPods, listed in the category "potential problem", are today energized by lithium-ion batteries due to the advantages provided by this technology. Also, the batteries of new devices are not removable. For this reason, they would be prohibited in hyperbaric chambers if this guideline would be applied.
- To complete what is said above, laptops and cell phones sold today are much more powerful than those available 15 years ago. As a result, the maximum power recommended in this guidance would be insufficient to energize them efficiently.
- Cathode ray tube TV monitors are no longer sold and replaced by Liquid Crystal Display (LCD) monitors.

These changes resulting from technological advancement are discussed further in the next points.

4.2 - QinetiQ - "A risk-based investigative study into the safety implications of using lithium-ion batteries in hyperbaric treatment chambers & saturation diving compression chambers" (July 2015)

QinetiQ says that the purpose of this report is to identify and assess the risks to the life of operators using Lithium-Ion battery (LIB) powered devices in saturation diving chambers and Deck Decompression Chambers (DDC) and to analyze

the International Marine Contractors Association's (IMCA) guidance D 041 on the use of lithium-ion batteries as power sources for consumer electronic devices in the hyperbaric environments.
This report leans on the fact that no incident record regarding the use of lithium battery-powered devices in hyperbaric chambers has been reported at the date of publication of the document, although a lot of diving contractors do not enforce the prohibition on the use of such devices recommended in IMCA D 041 and that many others consider it impossible to enforce an effective prohibition rule.

To identify and assess the risks of lithium battery-powered devices and publish relevant recommendations, QinetiQ has conducted a literature review and interviews with more than twenty Subject Matter Experts (SMEs) to gather the evidence necessary to construct a hazard analysis, perform a risk classification, and elaborate control measures.
As a result of this analysis, QinetiQ estimates the probability of a lithium-ion battery-powered device being involved in an energetic event is less than 1 in 21.3 million devices so that the probability of such an undesirable event is very low (as suggested by the aviation transportation report in point 3.1.3.2). So, the residual risk rating can be considered "acceptable", subject to implementing the recommended control measures and mitigation.
To conclude, QinetiQ says that using portable devices powered by lithium-ion batteries in hyperbaric chambers is safe as long as the recommendations indicated in the document are implemented. QinetiQ also says that the IMCA guidance D 041 should be updated at the earliest opportunity.

QinetiQ's recommendations are based on a risk assessment taking into account hazardous conditions arising from lithium-ion batteries used for portable electronic devices using reduced voltages such as MP3 players, digital cameras, hand-held games consoles, tablets, laptops, personal gas monitors, and other similar devices. We can summarize them as follows:

- *Recommendation 1:*
  The small scale hyperbaric cycling testing of a selected number of battery types from major manufacturers, in helium (to show that the batteries are resilient to both the pressure and the helium ingress) could be carried out in order to add confidence to the conclusion of this report.
  - Explanations and comments:
    QinetiQ says that people raised the concern that there may be a risk that helium diffuses into a battery during a heliox dive, which may cause this battery to expand and potentially burst during the relatively rapid decompressions that occur in medical locks, compared with the more gradual compressions/decompressions of the chambers containing diving personnel. It was felt that the likelihood of such an event might increase if these devices are exposed to saturation (Heliox) diving atmospheres for lengthy periods of time.
    To answer this concern, QinetiQ's Advanced Batteries Division said that the probability of this occurring during a short period is very limited. Also, even though helium penetration may occur over a long period of time, the quantity of gas that would enter the battery would not be sufficient to cause an undesirable event during decompression because the batteries are assembled with very little or no free space. Thus, this recommendation can be used to add confidence to this evaluation of the risk.
- *Recommendation 2:*
  All modified and non-Original Equipment Manufacturer (OEM) repaired devices to be prohibited from the chamber environment, only allowing OEM devices in original condition to be used.
  - Explanations and comments:
    QinetiQ considers that the batteries of small devices, such as mobile phones, are contained in hermetically sealed units that are considered sufficiently robust to withstand repeated hyperbaric compression & decompression cycles. This assumes that the batteries are compliant with recognized industry standards and are marked with relevant certification marks. However, QinetiQ considers that the integrity of non-OEM batteries cannot be guaranteed as their build quality is questionable. For this reason, QinetiQ says that the purchase of such batteries should be discouraged and not permitted for use within a chamber.
    QinetiQ also says that there are numerous replacement charging devices available for lost or damaged original devices. Some of these charging devices are untested and may not be safe enough to withstand the environmental hazards in a maritime workplace. For this reason, charging devices without recognized testing certification marks should not be permitted unless specifically authorized and certified.
- *Recommendation 3:*
  The operation of lithium-ion battery powered devices during both the initial compression to depth and the final stages of decompression (oxygen rich) should be limited to essential use only, i.e. the use of Lithium-ion battery entertainment devices is prohibited when in the "Fire Zone" as they cannot be deemed essential, as stated in the US Navy Diving Manual.
  - Explanations and comments:
    QinetiQ reminds us that a fire will not start when the oxygen percentage is below 6%, regardless of partial pressure. However, a spark is sufficient to ignite cotton overalls in an atmosphere where the oxygen percentage is 21%, but the partial pressure (PPO2) is over 700 millibar. The higher levels of oxygen percentage (>21%) during a saturation dive occur during the initial compression and the final stages of decompression. During most of the dive, the oxygen levels are below 6%. However, note that the Deck Decompression Chambers used for surface decompression and medical treatment are usually above 21% oxygen due to oxygen leaks during the decompression or the hyperbaric treatment.
- *Recommendation 4:*
  To prevent incidents occurring in an area of excessive dampness and humidity, the recommendation is to

damp conditions, such as the diving bell, and transfer chamber (transfer lock).

- Explanations and comments:
  QinetiQ explains that most electronic devices are not waterproof or capable of operating effectively or safely in the very humid atmospheres found in the bell or the transfer lock. For this reason, the authors of this recommendation consider it necessary to prohibit the use of these devices within those sections of a hyperbaric diving system unless the device is specifically designed for such conditions (i.e., splash or waterproof). Note that these waterproof devices will have to be opened during the phases of compression and decompression not to be crushed by the pressure or explode.

- *Recommendation 5:*
  It is recommended that certification marks (usually found on the exterior of lithium-ion batteries) should always be checked to ensure that they include the standards of test and that the applicable certification is in order. The aim is to establish the levels of compliance and safety of a device. Such a check would primarily be the responsibility of the personnel using the devices, but the dive supervisor can also check them prior to entry to the chambers. This will help establish if the devices are Original Equipment Manufacturer (OEM) equipment, are from reputable manufacturers and are built to internationally recognised standards.
  - Explanations and comments:
    This recommendation is a complement to recommendation #2. However, even though it was easy to implement it with the previous generation of cell phones (QinetiQ published this study in 2015), it is difficult or impossible to implement it with those currently sold. The reason is that batteries were accessible from the back of the devices with the previous generation of phones, so the users could easily access and remove them. That is not possible with the new phones and tablets as the batteries are embedded and glued inside them, so the devices' touch-screens have to be removed to access them, and the glue or the adhesive band must be taken off to detach them. As a result, only trained people can change these batteries. Of course, that does not eliminate the fact that non-Original Equipment Manufacturer (OEM) equipment can be installed in place of the original one by a phone technician.

Cell phone with removable battery (manufactured in 2012)

Tablet 7” with non-removable battery (manufactured in 2016)

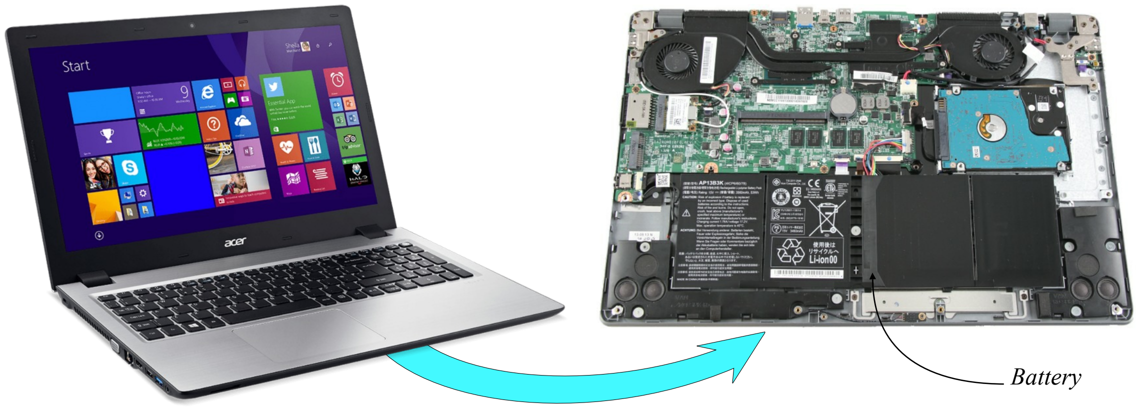
- *Recommendation 6:*
  We recommend procedures to ensure crew within the chamber are not developing and utilising elaborate techniques to conduct charging of equipment within the chamber, such as the using of the USB ports on a laptop and other devices with USB ports, or using aftermarket devices to provide a charging power supply.
    - Explanations and comments:
      Charging phones or tablets is considered a phase where the risks of fire are more elevated. For this reason, this activity should not be performed within chambers.
      QinetiQ says that charging devices within chambers is common today, with laptops and other USB sockets used to charge phones. Additionally, some divers use the bed lightings to charge the devices with an adaptor plugged into a bulb socket.
- *Recommendation 7:*
  We recommend that the Hazard Log is maintained and regularly reviewed to ensure that it still represents the current scenario.
    - Explanations and comments:
      QinetiQ says that to reduce the risks to a tolerable level, it is emphasized that the defined mitigations must be implemented as discussed in the meeting and documented in the Hazard Log (Hazard evaluation).
      QinetiQ also says that any deviation from these mitigations will invalidate this qualitative risk assessment. In addition, they say that the application of mitigations does not guarantee that a catastrophic event will never happen.
- *Recommendation 8:*
  It is recommended that this study is updated at least once every 3 years in order to understand the effects of new technology when used in diving chambers, and the impact of control measures implemented for the use of devices as a result of this report.
    - Explanations and comments:
      QinetiQ explains that there is a risk that the pace of technology advancement may rapidly change the size, shape, and power density of the batteries available for use in mobile phones and consumer electronic devices, rendering the findings of an investigation obsolete. It is what has happened to the document IMCA D 041 that has been written 15 years ago, which is like an eternity regarding electronic devices. It is also the case with this study, as demonstrated in the comments of recommendation #5.
- *Recommendation 9:*
  It is recommended that the total lithium-ion battery power density contained within a single device should be restricted to a maximum of 100 Wh to reduce the effective energy release in the event of a catastrophic lithium-ion battery failure.
    - Explanations and comments:
      QinetiQ says that a power density limit of 100 Wh is considered the best practice by the airline industry. Restricting the size of the battery to below 100 Wh will reduce the magnitude of an energetic event, potentially limiting an explosion to a fire scenario. This measure may not prevent a catastrophic event. Still, it can increase the crew's ability to escape safely and take remedial action against the fire.
      Note that electric charges of batteries are usually provided in milliamp-hours (mAh). To convert mAh to Watt hours (Wh), apply the following formula: Watt-hours = milliamp-hours × volts / 1000.
- *Recommendation 10:*
  It is recommended that a simple condition check of all devices taken into a chamber be conducted on entry.
    - Explanations and comments:
      QinetiQ considers that all batteries/devices built by reputable manufacturers are sealed units and are robust enough to withstand repeated hyperbaric cycling; however, this cannot be guaranteed. Hyperbaric cycling tests would need to be completed to assure their safety for use in chambers. Battery inspection (where access is possible) is vital to detect early signs of deterioration. Any batteries identified as defective should be removed and replaced with Original Equipment Manufacturer (OEM) approved replacements.
      This recommendation is a complement of recommendations #2 and #5. My comments are those of recommendation #5.
- *Recommendation 11:*
  It is recommended that the charging of lithium-ion battery powered devices or lithium-ion batteries within saturation diving chambers and deck decompression chambers is prohibited as this has been identified as the activity that presents the most risk of a catastrophic lithium-ion battery failure.
    - Explanations and comments:
      This recommendation is the complement of recommendations #2, #6 & #10.
      QinetiQ says that overcharging or a faulty charger could cause a failure in the battery leading to an energetic event. For this reason, it is preferable to refill the batteries outside the chamber.
      However, QinetiQ says that such an operation requires transferring the batteries/devices through the medical lock, increasing compression, and decompression cycles. Although QinetiQ considers that batteries and devices built by reputable manufacturers are sealed units robust enough to withstand repeated hyperbaric cycling, they say that this cannot be guaranteed and that hyperbaric cycling tests would need to be completed to ensure their safety for use in chambers.
      QinetiQ also says that battery inspection (where access is possible) is vital to detect early signs of deterioration. Also, any defective unit should be removed and replaced with an Original Equipment Manufacturer (OEM) approved replacement. The authors of the recommendation also suggest ensuring

that divers do not elaborate charging methods in the chamber.
My comments regarding the control of batteries are those of recommendation #6. Also, note that it is complicated to ensure that divers are not refilling their cell phones through laptops' USB ports. The only solution is to ensure that USB cables are not transferred within the luggage of the divers.

- *Recommendation 12:*
  It is recommended that suitable Personal Protective Equipment (PPE) is provided in all chambers where lithium-ion battery powered devices are used (i.e. heat and solvent resistant gloves to handle casualty batteries or devices; BIBS etc.).
  - Explanations and comments:
    A burning lithium-ion battery emits extreme temperatures in addition to pollutants. For this reason, it cannot be manipulated with classical gloves. "Polybenzimidazole" fiber gloves that can resist temperatures up to 700 Cº seem the most efficient currently sold. Also, tongs similar to those used by blacksmiths are antique efficient tools to manipulate burning items. Note that hyperbaric extinguishers and the Built-In Breathing System (BIBS) are supposed to be ready at all times.
- *Recommendation 13:*
  It is recommended that all relevant staff should be trained in the potential consequences of bad practices when using lithium-ion battery operated devices. It is imperative that adequate training is provided.
  - Explanations and comments:
    QinetiQ suggests organizing training for all hyperbaric and diving staff to address a lithium-ion battery fire situation that includes preventative procedures in the preparation and use of lithium-ion battery-powered devices within a chamber, in addition to emergency response techniques.
- *Recommendation 14:*
  It is recommended that a separate facility (external to and away from the vicinity of a saturation diving chamber or Deck Decompression Chamber) is established for the recharging of batteries remote from the chamber. This should prevent an energetic event from causing harm to personnel within the chamber.
  - Explanations and comments:
    QinetiQ highlight the fact that there is a risk that the adjacent area to a device being charged may be damaged from overheating or fire if a charger fault causes an energetic event.
- *Recommendation 15:*
  The provision of an alternative power supply within chambers and the attendant removal of device batteries (such as from laptops or medical equipment) as seen at Chichester hospital HTC is recommended.
  - Explanations and comments:
    QinetiQ refers to the Hyperbaric Treatment Chamber (HTC) of St Richards Hospital, Chichester (UK), in which operators actively prohibited the use of lithium-ion-powered devices at the date of publication of the report. The report says that medical handheld equipment used in the chamber was modified to run from a power supply that was pre-transformed externally and then supplied inside at the lower voltage/level. This arrangement was similar to the one on the photo below that shows a small laptop supplied by an external supply block that is working with the battery block removed. Thus, the external supply block is plugged into the 220 volt electrical supply, and the 19 volt DC output cable from the supply block supplies the laptop without passing through any battery. Thus, we can say that such a system is not difficult to implement, as the 19 volt supply could be transferred inside the chamber through a penetrator.

However, if making a laptop working without a battery and then adapt it to a hyperbaric chamber was easy with the models available before 2015; it was already not possible with the models of cell phones sold at this time that needed to have their lithium-ion battery in place to start and could not be started if the battery was damaged or discharged.
Based on the fact that the latest generations of laptops are built on similar designs to cell phones, making them work without a battery would be more complicated or impossible because their batteries are now embedded inside the devices. Of course, a trained technician can access such a battery by unscrewing the laptop's bottom cover, as we can see in the photo on the next page. Nevertheless, following discussions

with computer specialists, it appears that some of these portable computers might work without a battery after a modification and that some others will not start.



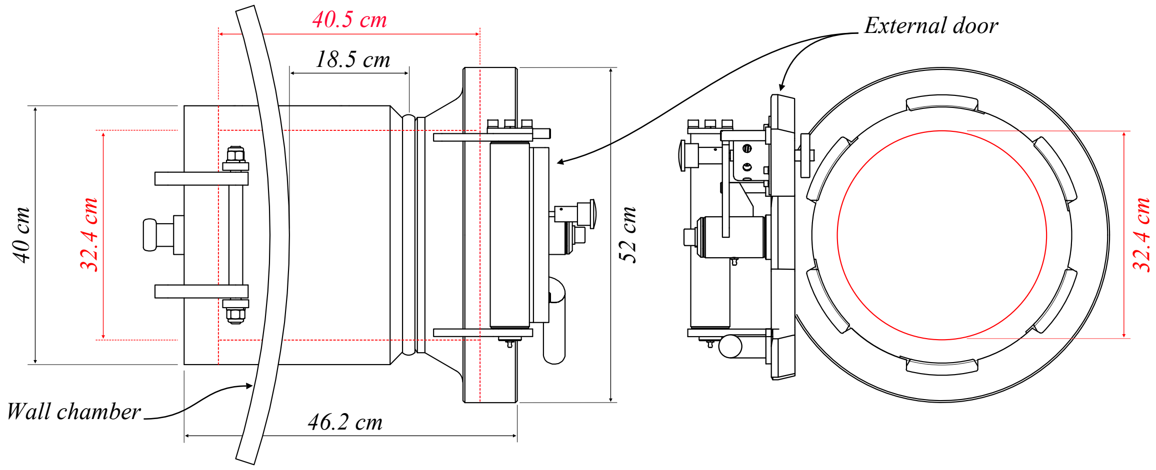
Based on what is said above, we can say that implementing such a process of modifications with the latest generations of multimedia equipment may result in unsuccessful attempts and limit the devices that can be transferred inside hyperbaric chambers to a few models specifically designed for this purpose. For these reasons, this solution can be considered only with devices belonging to the company.

- *Recommendation 16:*
  Where possible, the use of alternative types of battery (non-rechargeable) is recommended for all devices used within saturation diving chambers and deck decompression chambers (also called Hyperbaric Treatment Chamber), as this will completely remove any risk associated with lithium-ion batteries.
  - Explanations and comments:
    This procedure is also recommended in IMCA D 041. It would be complicated, or probably impossible, to implement it for the reasons already explained above (batteries of new generations of laptops and cell phones are not removable), the fact that alternative types of batteries would need to have shapes corresponding to the original slots of the devices they are supposed to energize. Also, batteries 2 or 3 times bigger than those originally designed for the devices would be necessary to provide the same working times depending on the models. As for the solution above, this option should be limited to devices belonging to the company if implemented.
- *Recommendation 17:*
  It is recommended the number of devices within the chamber complex is monitored and everything practicable is done to ensure that they are kept safe and used in accordance with the manufacturers' operating instructions, so that the safety of these devices is a priority at all times.
  - Explanations and comments:
    QinetiQ says there is a risk that a lithium-ion battery powered device may inadvertently be damaged within the hyperbaric chamber. As a control measure, it is proposed to make an inventory and monitor the devices using lithium-ion batteries within the chamber.
- *Recommendation 18:*
  It is recommended that all lithium-ion battery powered devices are switched off whilst not in use, with particular attention to transference through the medical lock.
  - Explanations and comments:
    QinetiQ specialists say that switching off the devices is a straightforward and effective way of securing them. The reason is that the batteries are isolated while switched off, which prevents the possibility of short circuits and further undesirable events whilst the device is unattended.
    In addition to what QinetiQ says in this report, a common practice was removing the batteries from the apparatuses. However, as previously explained, this is not possible with the devices of the latest generation.
- *Recommendation 19:*
  It is recommended that the total prohibition of all backlit Liquid Crystal Display (LCD) laptop screens within hyperbaric treatment and saturation diving chambers is strictly enforced. The prohibition of backlit LCD laptop screens should be included in the update of the guidance issued to IMCA members.
  - Explanations and comments:
    QinetiQ explains that the Liquid Crystal Display (LCD) screens of the very early laptops were prone to failure in hyperbaric conditions, resulting in short circuits in these devices.
    Regarding this recommendation, it must be highlighted that these portable computers are obsolete and no longer in service today.
- *Recommendation 20:*
  It is recommended that a suitable practicable maximum rate of compression / decompression is established and mandated for batteries and devices being transferred to and from the chamber.
  - Explanations and comments:
    QinetiQ says that despite their robustness, the structure of batteries may be affected by repeated fast compressions and decompressions. For this reason, it is expected that establishing maximum compression & decompression rates would prolong the life span and reliability of the batteries.
    Note that the authors do not indicate any specific descent or ascent rate.

- *Recommendation 21:*
It is recommended that the use of the "hot box" is discontinued, on the grounds that the current 'hot box' could be introducing additional hazards. Personal protection Equipment (PPE) is required as part of the standard equipment needed to handle a casualty device (see Recommendation 12).
    - Explanations and comments:
    QinetiQ specialists say that some companies made steel boxes designed to transfer failing devices that may introduce additional hazards because they are not properly tested and approved for this purpose. They also say that IMCA members who took part in a hazard evaluation meeting considered that the best option is to don protective gloves and remove the malfunctioning device into the medical lock as quickly as possible.
    The comments we can make regarding protective gloves and tools that can be used are those already made for recommendation #12. However, I am not sure that transferring scalding items into the medical lock will not damage it. Thus cooling the device before this operation could be a better idea.
    This topic is also discussed in recommendation #22.
- *Recommendation 22:*
The recommendation is that a blast resistant container, such as an ammunition box or similar box, which is specifically designed and tested to provide safe containment of potential energetic events, is used.
    - Explanations and comments:
    In complement to recommendation #21, QinetiQ specialists say that ammunition boxes can be used to contain the heat generated by an energetic event and transfer the device through the medical lock. They argue that these containers are not sealable or heatproof but are designed to contain all debris from an energetic event up to the United Nations explosives shipping classification system of 1.4 (minor explosion hazard). They also add that these boxes can be fitted with fire and heat resistant or insulating material that may help to contain the heat generated by an energetic event or filled with water.
    This solution can be considered suitable, provided that these boxes can contain the apparatus present in the chamber and can be transferred through the medical lock. As an example, the following ammunition boxes dimensions can be found on the Internet:

Ammunition	*Length*	*Height*	*Width*
5.56 mm NATO	30 cm	22 cm	16 cm
7.62 mm NATO	26 cm	16 cm	11 cm
12.7 mm NATO	28 cm	18.5 cm	16 cm
20 mm NATO	33 cm	34.5 cm	14 cm
40 mm NATO	44 cm	25 cm	16 cm

The medical locks of the saturation systems of UDS Lichtenstein and Picasso have an internal length of 40.5 cm and an internal diameter of 32.4 cm (see in red in the drawing below).



We can see that some of these ammunition containers cannot be used because they are too high or/and too long. It is the case of the boxes designed for calibre 20 mm and 40 mm. The other boxes of this list can be used for cell phones and tablets 10", but they are too small for most laptops. For example, devices with a 14" screen are approximately 32 cm long & 22 cm in width. That obliges to use smaller models with 10 or 11" screens whose external dimensions are approximately 25 cm long & 19 cm in width. So, even though this solution is efficient, it is not perfect. For this reason, a better solution is to provide fire containment battery bags designed to carry spare lithium batteries and portable electronic devices in aircraft and are promoted by the aviation industry. The configuration of these bags consists of high-temperature insulation & fire-resisting materials that are able to withstand the explosive release of energy and cell combustion as a result of a lithium-ion thermal runaway. These bags are sufficiently wide to contain laptops, so the only problem is to ensure that the device in the chamber can be transferred through the medical lock. Note that these bags can also be used to store the electronic apparatus when they are not used.

Additional QinetiQ recommendations for fire fighting:
In addition to the recommendations above, QinetiQ says that reputed safety organizations state that a water-based fire extinguisher is the most appropriate method for tackling a lithium-based fire because the water will cool the lithium and prevent the battery from rupturing and venting gases. In addition, it is considered that in the event of a battery rupture, water will help to contain any fluid leakage from the battery, and the water vapour in the air will help to reduce the risk of acidic gas. Regarding this guideline, note that the extinguishing agent of chamber extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for any fires, including electrical fires up to 24 Volts.

QinetiQ completes its report by a risk assessment where the elements from the recommendation above are integrated to the fire fighting procedures and abandon saturation system procedures.

4.3 - To conclude with these guidelines

The reports IMCA and QinetiQ described in the previous point are more than 6 years old. Thus, they are outside the recommendations of QinetiQ, which suggests updating guidelines related to electronic apparatus every 3 years. That shows the difficulties of implementing such a process. However, both documents highlight potential hazards linked to the use of battery-powered portable electronic devices in hyperbaric chambers and suggest control measures that can be used for the assessment of the policy of the company. Other data from various professional associations, safety organizations, and certification bodies should also be used.
Note that the following facts that are also discussed in the comments of the recommendations of both documents have to be considered in the evaluation of risks and for the selection of the procedures:

- Lithium-ion batteries power today the totality of laptops and cell phones.
- Cell phones have replaced a lot of devices, including video games, clocks, calculators, and others.
- Since the publication of the QinetiQ report in 2015, the efficiency of lithium-ion batteries has been increased in terms of durability, energy storage capacity, and refilling speeds that are today two-three times faster than the units sold in 2015. That is linked to the fact that the electronic industry is a very competitive world where performances, innovations, and ease of use are essential to attract clients. For this reason, it may happen that despite the certification tests, some devices are not as robust as planned.

These facts demonstrate the importance of being aware of the industry's progress and implementing procedures for this.

5 - Evaluate the likelihood of occurrences

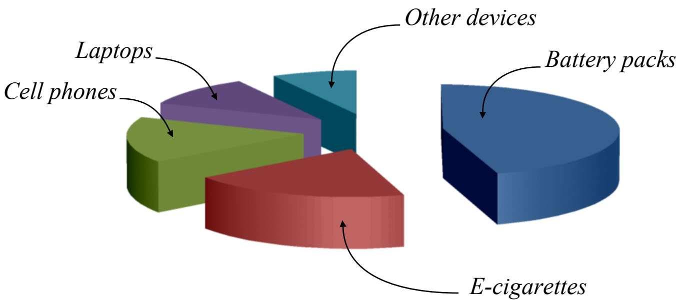
The investigation of occurrences must be based on reports from recognized organizations that precisely report facts. Thus, articles from the mainstream press, which are often insufficiently documented, are not reliable sources. Nevertheless, some of these articles highlight events to investigate further.

As said in point 4.2, QinetiQ estimated that the probability of a lithium-ion battery-powered device being involved in an energetic event was less than 1 in 21.3 million devices in July 2015. Considering the quality of this report, we can think that this estimation was based on reliable sources. This report also said that no incident happened in a hyperbaric chamber at its publication date. Regarding this fact, there is still no incident indicated in chambers by professional organizations such as IMCA, ADCI, and others since the date of publication of this QinetiQ report. However, the probability that such an event happens exists. For example, a few incidents are reported in the IMCA safety flashes, with some of them are from other organizations. They can be summarized as follows.

IMCA safety flash & Sources	*Description*
IMCA Safety Flash 29/18 / United States Bureau of Safety & Environmental Enforcement	Fire in the living quarters of a drill ship (March 2016): The fire was supposed to have started from a universal adapter plugged into a light fixture where a phone charger was plugged in and/or from a tablet left under the bunk's pillow.
IMCA Safety Flash 16/16 / Marine safety forum	Fire in a crew member’s cabin on a vessel caused by the overheating of a battery. The crew member who was not in his cabin at the time, had left a power bank charging and unattended.
IMCA Safety Flash 24/16	Fire in a vessel accommodation due to an overheating notebook computer. It appears that the notebook computer was inadvertently turned on whilst laying on a bunk bed, and this reduced the efficiency of the cooling fan which caused the computer to overheat.
IMCA Safety Flash 27/17	A laptop battery exploded and caught fire. The device was switched off at the time but was on charge at the mains.
IMCA Safety Flash 29/18 / United States Bureau of Safety & Environmental Enforcement	Fire in temporary living quarters that started from a cell phone charging on a mattress. The charger wire apparently failed, creating enough heat to ignite the bed sheet and mattress.
IMCA Safety Flash 29/18 / United States Bureau of Safety & Environmental Enforcement	Heat damage to the ceiling and lights of a room, as well as multiple mattresses. The possible cause of the fire was a tablet being charging on a bunk.
IMCA Safety Flash 18/18	A phone left charging caught fire that extended to the cabin and triggered the fire alarm.
IMCA Safety Flash 25/19 / Norwegian Maritime Authority or *Sjofartsdirektoratet*	A fire incident occurred in a seafarer’s cabin due to a faulty mobile phone charger. The charger was left plugged in while unattended and an electrical short circuit ignited some paper on a desk.

Note that of eight fire events indicated, seven were attributed to cell phones and tablet charging. However, there are not enough incidents reported in these safety flashes to edit relevant statistics. For this reason, these incident reports must be completed with more data.
For the moment, there is no database of such incidents from the diving industry. However, a reliable documented source is the air transportation industry that is more exposed to such events due to the high number of flights organized daily. As an example, the Federal Aviation Administration (FAA), which regulates all aspects of civil aviation in the USA, regularly updates such incident records on a document called "Events with smoke, fire, extreme heat or explosion involving lithium batteries" that can be downloaded on the Internet:
This document indicates 247 spontaneous fires attributed to electronic equipment powered by Lithium-ion batteries in American airports and various planes (passengers & cargo) moving to or from these airports between January 2015 and June 2021.
Considering that more than 1.25 billion passengers and more than 60 million tonnes of cargo have been transported by air during this period from or to airports situated in the USA, we can say that the number of occurrences remains very low. However, we need more information than only this comparison that does not indicate the types of apparatus responsible for these spontaneous fires and the conditions that triggered these events.
This is possible with this document as it indicates a sufficient number of events to create statistics. As an example, the devices responsible for fires or associated occurrences can be classified as follows:

Items	***Nb of incidents***	***Percentage (%)***
Battery packs	112	45.3
E-cigarettes	48	19.4
Cell phones	40	16.2
Laptops	27	10.9
Other devices	20	8.1

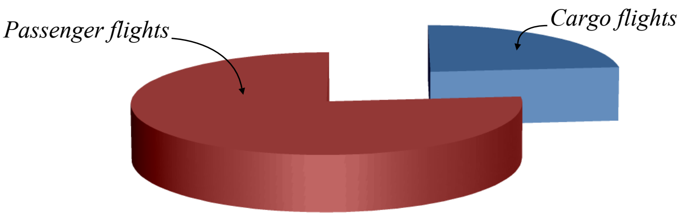


Clarifications regarding the classifications above:

- "Battery packs" are power banks for cell phones and tablets, but also ensembles of batteries for other applications such are medical equipment, cars and others. The incident classified "battery packs", involve these devices only.
- "Other devices" are apparatus, such as medical devices, gas analysers, entertainment equipment, etc.
- "Cell phones" includes cell phones and tablets.

Note that 64.7% of the incidents are from battery packs and e-cigarettes. Also, cell phone and laptop occurrences represent 27.1% of the total, but this point must be further detailed.
Smoking "E-cigarettes" is normally authorized only in the smoking room. However this report indicate that they may be sources of fire when not used. For this reason, strict control measures have to be implemented.
Another clarification process is to separate events that happened during passenger flights from those during cargo flights to provide rates for these events by the number of passengers and tonnes of goods transported:

Types of flights	***Nb of incidents***	***Percentage (%)***
Cargo flights	58	23.5
Passenger flights	189	76.5



Clarifications:

- "Cargo flights" consists of sudden fires events during loading and offloading phases and during the flights. Note that the incidents recorded between 01/01/15 and 30/06/21 happened during the preparation phase of cargos and offloading operations. Nothing is indicated during flights.
- "Passenger flights" consists of sudden fires happening during the flights and the boarding and disembarkation processes of the passengers in the airports.

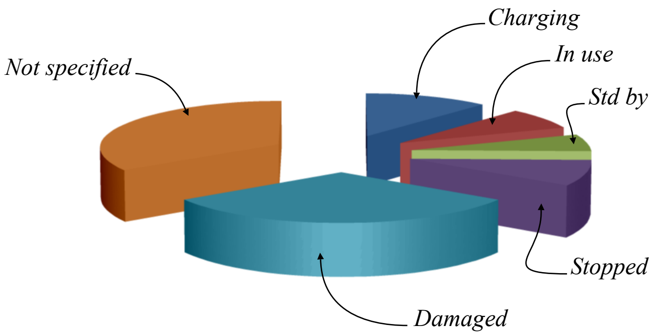
We can say that approximately 189 incidents are recorded for 1.25 billion passengers and that 58 incidents are recorded for 60 millions tonnes of cargo transported during the period of time considered.
Also, as battery packs are the most involved in fire events, it is interesting to see whether these incidents happened mainly with passengers or during cargo flights operations. The records of this document indicate 42 incidents liked to battery packs during cargo operations (37.5%), and 70 incidents linked to passengers flights and their embarkation & disembarkation processes (62.5%).

We can also say that only 59 incidents involve cell phones and laptops during passenger flights and their embarking and disembarking phases. However, other data should be extracted to understand better the reasons that have triggered spontaneous fires of cell phones and laptops. That can be done by classifying the status of the devices when the incident happened, as in the example below:

- "Device charging" is when it is indicated that the apparatus was connected to a battery pack or a charger. The device could have been stopped, started but not used, or in use (statuses are unclear in some reports).

- “In use on battery” is when the incident happened to a machine at work, but not charging
- “Standing by” is when the apparatus was open but not actively used and not connected to a charger. It is the status of cell phones during the major part of the day.
- “Stopped” is when the device was indicated as stopped and not connected to a charger.
- “Device damaged” is when the machine was not connected to a charger, and the fire spontaneously started immediately following a drop or damages to its structure.
- “Not specified” are the incidents where none of the above conditions is clearly indicated in the report. Thus it was possibly due to one of them but also several of them cumulated.

Items	***Nb of incidents***	***Percentage (%)***
Device charging	8	11.9
Device in use	5	7.5
Device standing by	4	6
Device stopped	6	9
Device damaged	21	31.3
Not specified	23	34.3



We can see that the most identified scenarios are from devices charging and damaged, which represent 43.2% of the cases if grouped.
Regarding the damaged cell phones and laptops, note that seven of the twenty-one events reported were units crushed between the passenger's armchair's seat and backrest, which is equal to 1/3 of the scenarios. Also, two laptops started to burn after receiving water accidentally spilled.
In addition, we must take into account that 34.3% of the sudden fires reported are not documented regarding the status of the apparatus when the event happened. That represents approximately 1/3 of the cases, which is a lot.

The incidents can be more studied by detailing them by type of apparatus and manufacturer brands. However, too much data may not provide additional exploitable information, and may push the investigation team outside the purpose of this process, which is to be aware of the frequency of incidents arising from the devices considered.
We must also consider that there are some uncertainties regarding some causes of incidents. For example, an apparatus that starts to burn may have been damaged several days before the event. In addition, we need to take into account that the status of the apparatus before the occurrence is often indicated by its owner to the cabin attendants who write the report. Also, the authors of this incident list say the following: *“These are events that the FAA is aware of and should not be considered a complete listing of all such incidents”*. These uncertainties demonstrate the difficulties of establishing a relevant database.
Despite the problems highlighted above, these incident records from FAA are sufficiently documented to say that undesirable events arising from portable battery-powered apparatus are infrequent. However, the following elements are to be taken into consideration to prepare a suitable response to such incidents:

- Battery packs (power banks) are the devices the most involved in fire scenarios.
- Fires often start from damaged apparatus, and these damages are not always visible. Thus, a dropped object can suddenly burn even though there is no external damage.
- Another noticeable fire scenario comes from devices in the charging phase. This point is confirmed by the reports of incidents from the safety flashes IMCA and other organizations.
- The thermal runaway of a lithium cell can start with stopped devices.
- Considering the data above, we can say that only 15 incidents are reported for cell phones, tablets, and laptops not damaged or under a refilling phase, plus 23 events where the statuses of the devices are not precisely documented. That is to be compared to the 1.25 billion passengers transported during the period indicated.

6 - Implement preventive control measures

In point 4.1, it is said that portable phones, tablets, and recent laptops cannot be transferred in the chamber if IMCA D 041 (Oct. 2006) is applied. Company managers are free to apply this IMCA guidance strictly. However, as explained in the report from QinetiQ described in point 4.2, a lot of companies, many of them are members of this organization, do not apply it.

According to the QinetiQ report taken as a reference and the evaluation of the likelihood of undesirable events from portable battery-powered apparatus above, we can admit that using these devices in hyperbaric chambers is safe as long as preventive and corrective control measures are implemented. The problem is that even though the likelihood of an incident is infrequent, the consequences of such an event could be catastrophic.
The purpose of the preventive control measures described in this point is to ensure that incidents from portable battery-powered apparatus in the chamber will be As Low As Reasonably Practical (ALARP) if it is decided to transfer such devices in the chamber. These safety precautions are to be implemented for each phase of the saturation dive.

The divers must be involved in assessing and implementing the control measures and then fully adhere to them.

6.1 - Select the cell phones, tablets, and computers allowed in chambers

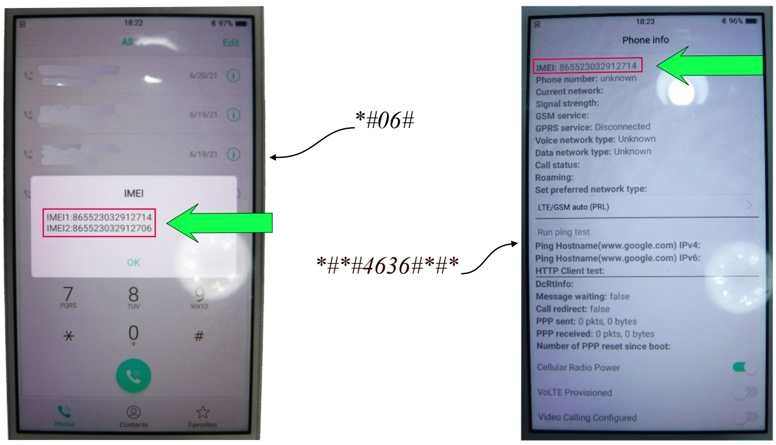
Cell phones, tablets, and laptops planned to be in the chamber must be checked to ensure safe use.
Two options can be implemented:

1 - The company supplies cell phones and laptops that have been tested suitable for use in chambers to the divers sufficiently in advance to let them set up the apparatuses with the software they like. At the end of the dive, the devices can be reset to the factory settings, reviewed, and reused by another diver. If the diver is working in rotation, the apparatus can be kept for his next saturation.
Despite its cost, this procedure has the advantage that the equipment transferred is fully under the company's control, and most QinetiQ recommendations are easy to put into practice.
However, as already commented in point 3.1.3.3.2, QinetiQ recommendations #15 and #16 (change the supply system) will be difficult to implement with the new generations of computers and probably impossible with most models and cell phones for the reasons already discussed.

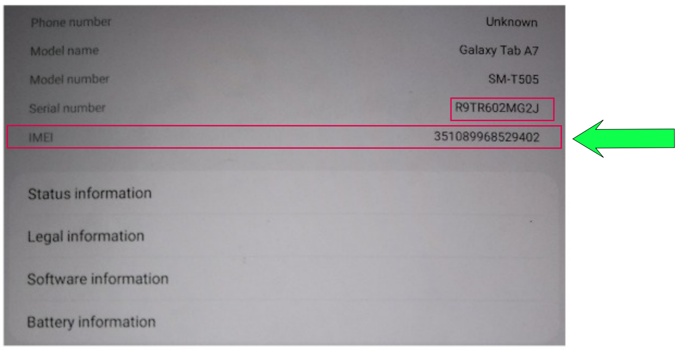
2 - The company authorizes the divers to use their personal devices. In this case, the team has to be organized to implement the recommendations as below:

- QinetiQ recommendations #15 and #16 are not applicable with personal computers of the latest generation as they require the opening and modification of devices that do not belong to the company. It is also the same case with phones that usually do not start without their original battery.
- As explained in the comments in point 3.1.3.3.2, recommendations #2 and #5 (checking batteries) were easy to implement with previous devices. Still, it is much more complicated with the latest generations because the batteries are today not accessible without opening the devices. However, it is possible to ensure that the batteries are original parts by limiting the age of the device agreed in chambers. This age can be controlled through code numbers sometimes displayed on the machine and always accessible through the operating system.

  The International Mobile Equipment Identity (IMEI) is a number attributed to each mobile phone and tablet that provides the name of the model, the name of the manufacturer, the year of fabrication, the serial number, the capacity of the battery, and much other information. If it is not indicated on the shell of the device, two methods can be used to obtain it:
  The 1st method consists of dialing *#06# or *#*#4636#*#* through the phone call program to display one of the two windows below.

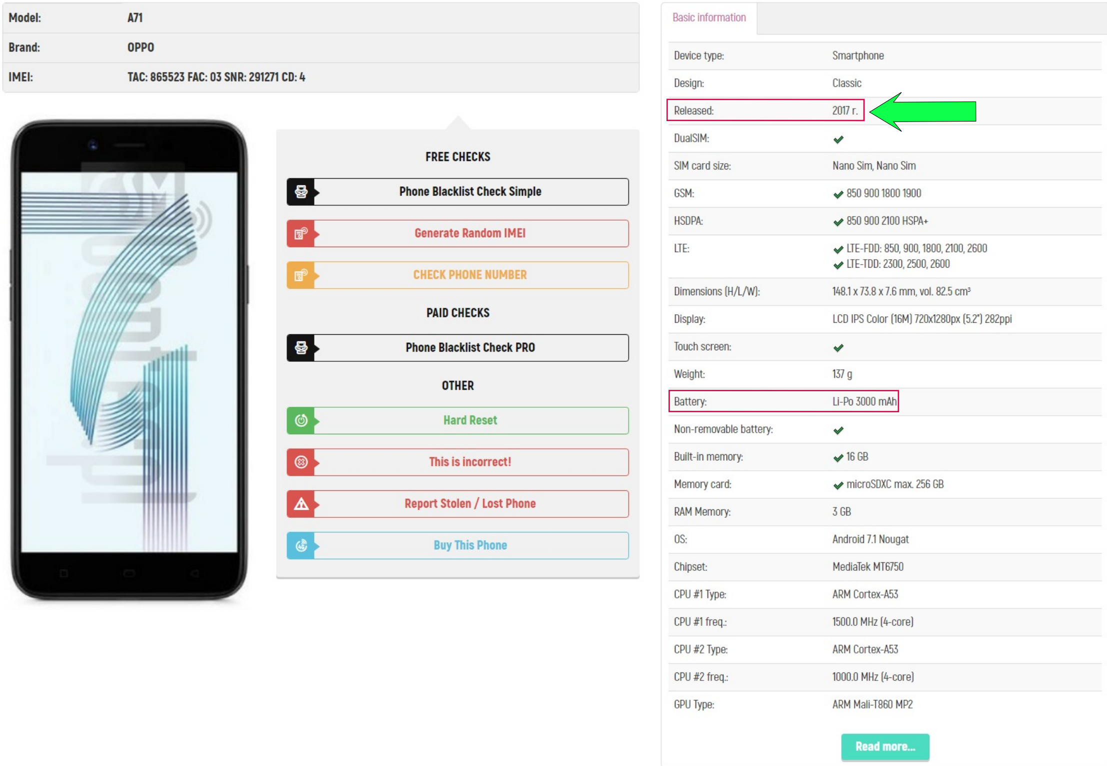


  The second method to access to the International Mobile Equipment Identity (IMEI) number is to do it through the function “settings” and then select “About tablet“ or “About device“. Usually that displays the required information as in the photo below. However, it is sometimes necessary to open the function “status” to access it. Note that the serial number is also displayed. This method can be used with Android tablets not provided with phone function.



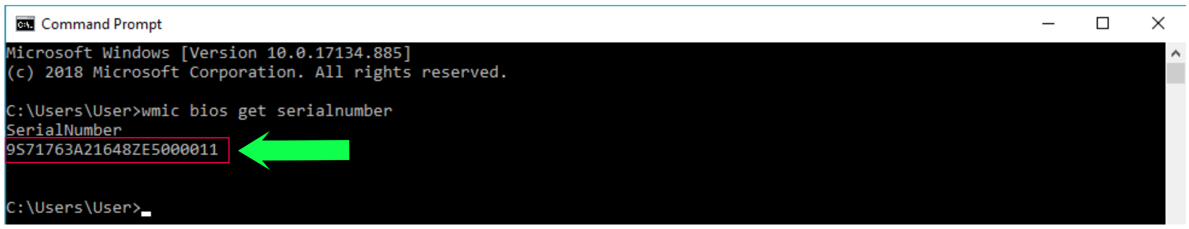
  IMEI code and serial number of I pads and other tablets Apple is possible using a similar process:
  From the home screen, tap the icon “Settings”. Then, tap the icon “General”. Then, tap the icon “About”. Then, scroll down to view the serial number and IMEI.

When the IMEI code is obtained, connect to the website https://www.imei.info/ (or a similar site), compose the IMEI code in the dedicated slot and click "check". The website then provides the characteristics of the phone or the tablet as displayed below.



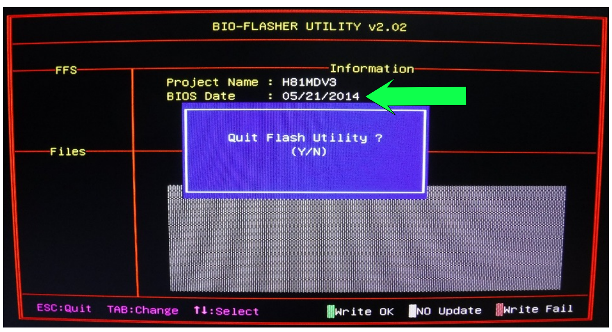
Note that some manufacturers provide the IMEI and serial number on the device's shell, but many of them (even the most reputed) do not do it. Also, a straightforward means of control is the invoice of the device where its IMEI code or/and serial number should be indicated.

IMEI system is not implemented for computers. However, laptop manufacturers using Windows and Linux OS also provide the serial number of the machines they sell on the device's shell.
This serial number can be used to check the age of the computer through the online support system of the manufacturer or using the invoice of the machine.
When the serial number is not visible on the machine, it can be found through the functions of the operating system:
The 1st step consists of opening the "Command Prompt" by typing *"cmd"* into the search box of the task-bar beside the "Start menu". The 2nd step consists of typing *"wmic bios get serialnumber"* and press the key "Enter". Then the program displays the information as below:

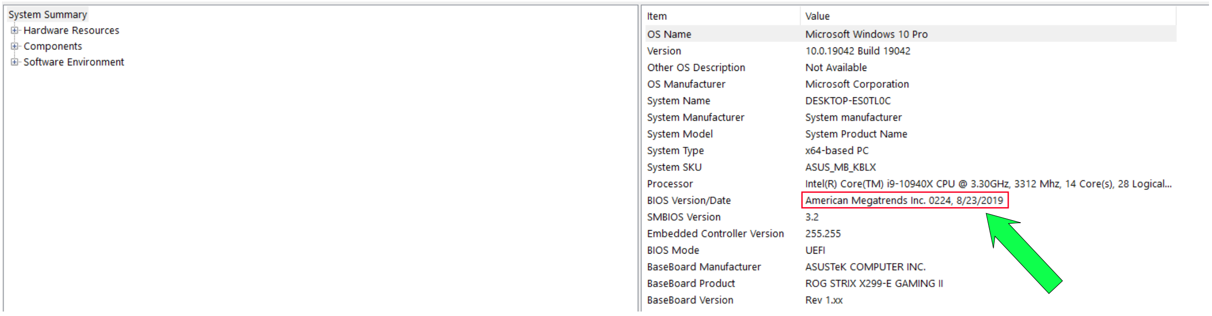


Note that attempts made with different brands' support systems to check the age of laptops show that the manufacturers' websites do not always provide relevant information. Also, it is often required to open an account to access the support program. That can make difficult the investigation from the boat or a facility. For this reason, it seems that asking the divers to keep the invoice of the machine where the serial number of the device is clearly visible is a better procedure.

Another method to find the age of a laptop is to check the date of the Basic Input/Output System (BIOS). The BIOS is the program a computer's microprocessor uses to start the system after it is switched on and manage the data flow between the Operating System and the attached devices.
This method is based on the fact that people do not update the BIOS of their machine as long as it works.
The 1st method to access the BIOS is by pressing the key briefly indicated when the machine starts.
Then the computer displays the information aside:

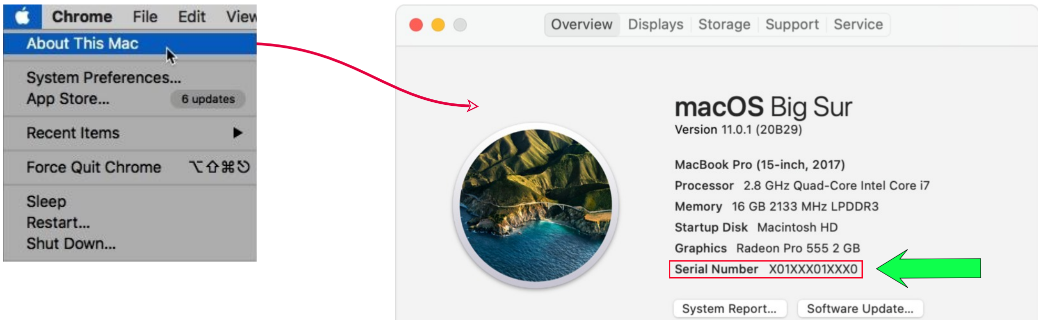


A second procedure that works with Windows OS to access the age of the bios in through the function "system information" . The 1st step consists of opening the window by typing *"system information"* into the search box of the task-bar beside the "Start menu". Normally the link to the program should appears in the window above the search box. Clicking on it should open the window below:



Note that the date of BIOS refers to the date of update. It is true that usually, this update remains the same all along with the life of the computer. However, the BIOS may have been updated if the machine has been repaired or if the machine's owner has knowledge in computing. In case of doubt regarding the age of a computer, and nothing is on-site that allows to check it using its serial number, the solution will be to unscrew its bottom shell to assess the battery.

The serial number of an Apple/Mac computer is often indicated on its shell. It can also be collected through the functions "About This Mac" and "System Information".
To access it, the operator clicks the icon "Apple menu" in the upper-left corner, and then opens "About This Mac", which provides an overview of the machine, such as in the picture below. To see more details, the operator can click the System Report button (below the serial number).



The serial number can then be checked on the website https://checkcoverage.apple.com/. However, as indicated above, using the bill from the reseller is maybe more straightforward.

- Limit the age of the devices in the chamber:
  As said previously, the reason for checking the age of last generation computers and cell phones is to ensure that their embedded batteries are genuine parts. This procedure is based on the fact that batteries of new devices rarely fail. Note that it is possible to change the battery of an old apparatus. Still, in this case, the operation must be certified by relevant documents from the manufacturer or one of his registered subcontractors (QinetiQ recommendation #2).
  Investigations regarding the maximum time a battery can last show that there is no officially published data that would allow us to evaluate such items' average life. Also, phone manufacturers avoid giving precise information regarding this matter for commercial and legal reasons.
  Several consumer organization websites say that cell phones typically last for around 2-3 years. But their investigations seem not based on precise data, or their sources are kept hidden. However, the website https://storymaps.arcgis.com that describes "the life of an iPhone from its conception to the end of its life" says that an iPhone's typical lifespan is about 4 years & 3 months. This website explains that the main reason for 4 years & 3 months limit is planned obsolescence.
  It seems that the renew frequencies indicated by consumer organizations are based on the same reasons and not on the real lifespan of batteries.

  Of course, as previously indicated in point 3.1.3.2, the fact that these devices will be submitted to repeated compression and decompression is not taken into account by the manufacturers. Regarding this matter, we can refer to the report from QinetiQ that says that even though helium penetration may occur over a long period of time, the quantity of gas that would enter the battery would not be sufficient to cause an undesirable event during decompression. QinetiQ recommendation #1 says that tests can be organized with several batteries to ensure that the batteries withstand repeated compression and decompression. Nevertheless, we can also consider that divers transfer cell phones and laptops in chambers for years and that no incident is indicated for the moment. Thus we can say that such tests have already been empirically made.
  Pressure tests may be useful on particular models that are indicated to have susceptibility to failures. However, the problem is to decide who performs these tests and how they are evaluated. It must be notified that for the moment, no diving organization has officially published the results of such tests, and none of them publish records of apparatus transferred in chambers.

Considering what is said above and the fact that many computers and phones continue to work satisfactorily past 5 years of age, we can say that limiting the age of devices transferred into chambers to 3 years appears reasonable. However, the method of control used must be taken into account:

- If the reference is the invoice, the date indicated is a valid reference.
- If the reference is the IMEI code and the date of the BIOS, more flexibility may be acceptable as the IMEI indicates only the year of production, and the update of the BIOS can have been done up to one year before the motherboard is activated.

- Set the maximum size of the battery
QinetiQ Recommendation #9 says that a device's total lithium-ion battery power density should be restricted to a maximum of 100 Wh, which is a logical restriction we should adhere to limit the effective energy released in case of a catastrophic event.
Regarding this matter, investigations through manufacturer websites prove that the most powerful laptops currently on the market remain below this limit.
- Appoint a competent person in charge of checking the devices:
Among people in charge of the dive system, the dive technicians are probably the most competent to check these appliances. However, they are usually very busy with the system, and it is not suitable to occupy them with operations that other people can easily do. For these reasons, they should be involved only when activities require technical knowledge to be performed, such as, for example, the opening of a laptop. If the procedures explained in the previous point are implemented, checking the IMEI codes and serial numbers do not require particular skills. Thus, a safety officer can be in charge of this operation. Checking these elements requires patience, imagination, and honesty.
- Record the devices accepted in the chamber:
The person in charge of the verifications must establish a clear list of the devices authorized in the chamber. This list should be accompanied by relevant folders that group copies of the invoices, detailed specifications of each device, photos, etc. A good system is to attribute a reference number to each device. This list and its attached documents should be sent to the Life Support Technician, the Diving superintendent, the safety officer (if the person checking the devices is someone else), and the Offshore manager. Also, it should be kept and shared for the follow-up of the machines registered for the next saturation.
To help the life Support Technicians to identify the devices during the operations, a self-adhesive sticker that displays the attributed reference number (thus, the proof that the device has been checked), and the name of the diver, can be provided on each apparatus agreed in the chamber.
- Cases of models susceptible to failure:
A particular model of phone or laptop may be more subject to sudden fires than the ensemble of apparatus taken into consideration for the likelihood of such events. These problems have been encountered with the most reputed brands and must be taken into account. However, they should be considered isolated events and not general events that may result in the divers suddenly not being allowed to transfer their devices in the chamber. For this reason, unless a study proves that the likelihood of such dangerous events has dramatically increased and affects the totality of devices, only the model affected must not be allowed in the chamber until further clarifications are provided. A note should be transmitted to the divers and the people in charge to ensure everyone is aware.
- Edit a database:
The list of devices in the chamber should be shared to establish a database. This database should be published so divers and people in charge are aware of it and enrich it.

6.2 - Set rules for other electrical and electronic devices

Rules must be established for other electrical and electronic devices and also charging devices of cell phones, computers, and other equipment:

- Small electrical and electronic devices:
As specified in IMCA D 041, small devices such as rechargeable torches, calculators, cameras, analysers, electronic clocks, shavers, toothbrushes, and similar small items do not represent any harm to the divers and can be transferred in the chamber.
- Electronic medical equipment:
These devices are allowed in the chamber provided that they comply with the specifications for cell phones, tablets, and laptops. Also, in case that their power supply is more elevated than these devices, it must be Direct Current (DC) less than 30 volts and the maximum voltage indicated on the hyperbaric extinguisher.
- Power-banks (battery packs):
Power banks, also called battery packs, are involved in the highest proportion of incidents reported in the document from the FAA taken as reference for analysing the likelihood of fires linked to Lithium-ion batteries. For this reason, and also because another recognized condition linked to sudden fires of cell phones and laptops is when they are charging, these items must not be allowed in the chamber.
- Cell phones, laptop or other equipment chargers:
As said above, a recognized condition linked to sudden fires of laptops and cell phones in the document from the FAA taken as reference for analysing the likelihood of fires linked to Lithium-ion batteries is when these devices are charging. For this reason, chargers must not be allowed in the chamber.

6.3 - Prepare the firefighting systems, tools, and procedures

Ensure that the fire fighting systems and tools are ready is essential to ensure that failures of electronic devices in the chamber will always be under control.

- Tools to control a battery powered apparatus burning must be provided:
  As already indicated in the comments of QinetiQ recommendation 22, "fire containment bags" designed to carry spare lithium batteries and portable electronic devices in aircraft must be provided with specific high temperature gloves to handle device starting a sudden fire.
  Note that these bags should also be used to store the electronic apparatuses when they are not used.
  The configuration of these bags consists of high-temperature insulation and fire-resisting materials that are able to withstand the explosive release of energy and cell combustion as a result of a lithium-ion thermal runaway.
  These bags are sufficiently wide to contain laptops, so the only problem is to ensure that the device in the chamber can be transferred through the medical lock.


  Among the manufacturers who can be contacted note: AVSax (http://avsax.com), and FEC Heliports equipment (www.heliportsequipment.com).
  As already commented, a burning lithium-ion battery emits extreme temperatures in addition to pollutants. For this reason, it cannot be manipulated with classical gloves. "Polybenzimidazole" fiber gloves seem the most efficient. Also, blacksmith tongs are antique but efficient tools for this purpose.
  There must be sufficient gloves available to manipulate the devices if a sudden battery fire scenario starts. Note that they should be some available outside the chamber.
- The deluge system, hyperbaric extinguishers, and the Built-In Breathing System (BIBS) are explained in the book "Description of a saturation diving system" by "Diving & ROV specialists". They must always be ready. It must be remembered that the extinguishing agent used in the hyperbaric extinguishers is an Aqueous Film Forming Foam (AFFF), which is suitable for fabrics, combustible solids, flammable liquids, and electrical fires up to 24 Volts. The operating process of the foam is that it makes a blanket that blocks oxygen supply and suppresses vapours. Also, the water content of the solution produces a cooling effect. Nevertheless, electrical devices in the chamber should be limited to the maximum voltage the extinguishing agent is designed for.
- Drills should be organized to train the team to throw an apparatus into a fire containment battery bag, transfer it outside the chamber through the medical lock, and remove it from the dive station. Scenarios where the fire extends to other items in the chamber, such as bedding, should be considered.
  Note that firefighting and abandon ship drills are mandatory for saturation teams.

6.4 - Organise the batteries charging station

As explained previously and demonstrated through the likelihood study, catastrophic lithium-ion battery failures that trigger sudden fires happen more often during the device's charging process than when the device is not connected. For this reason, the refilling of the apparatuses must not be done in the chamber, and a charging station must be organized. This is also in line with QinetiQ's recommendation #11.

- QinetiQ report 2015 suggested using Original Equipment Manufacturer (OEM) chargers. Regarding this point, note that recent cell phones use chargers 5 volts DC 1 to 2 amperes, which is the electricity supplied from the universal charging blocks found in hotels, cars, airports, offices, etc. The main difference is from the USB cords that are different whether the phone is an Apple or another brand. This is more complicated with laptops as the output voltage and amperage change from one model to another. For this reason, genuine chargers should be used with these devices.
- The charging station must not be organized at the direct proximity of the dive station, the vessel's machinery, the gasses, or a storage area. It must be in a place where people who may intervene quickly if a fire starts are present, and where a sudden fire has limited consequences and can be quickly solved. Means of fire fighting should be close to the devices with "fire containment battery bags" and high-temperature gloves.

6.5 - Set up safe practices in chambers

Implementing a suitable preventive safety also depends on the behaviour of people and the precautions in place in the chamber during the dive. For these reasons, strict rules must be established and implemented:

- Electrical and electronic apparatuses should be used for the tasks they are designed for only.
- Lithium battery-powered devices must be shut off and stored in their "fire containment bags" when they are not used. They should be stored in the lower parts of the chamber and away from flammable items.

- Devices that have fallen, are damaged, or are abnormally hot must be removed from the chamber. They may be allowed again after a close investigation of their condition.
- Devices should never be left unattended on flammable items such as bedding and similar.
- The divers should watch each other to avoid falling asleep with the apparatus open.
- Fire gloves and "fire containment bags”must always be available. It is also the case of the fire extinguisher.
- Recharging empty devices within the chamber must be strictly prohibited.
- Cell phones, tablets, and laptops must not be used in the moisten parts of the saturation complex, unless they are designed to withstand these conditions (waterproof phones).
- Electronic and electrical devices must not be used during the beginning of compression and the end of decompression phases, where the oxygen percentages are more elevated and may favor a fire. The green light to use them is given by the Life Support Supervisor (LSS) only.

6.6 - Implement precautions for the transfer of the battery powered devices through the medical lock

The uncertainty regarding the effects of pressurization and depressurization processes on the devices transferred must be considered. Also, transfer locks operations imply some risks that must be taken into account, in addition to the fact they consume heliox. The following precautions should be in place:

- Transfers operations to and from the chamber should be limited to a minimum and organized at regular times. The divers should be encouraged to buy products with long autonomy to limit the need for transfer to a minimum. Note that recent cell phones, tablets, and laptops allow for more than 8 hours of battery life at work.
- Electronic devices transferred to the chamber must be logged, so the Life Support Supervisor is aware of the devices in the chamber and those that are charging or stored outside.
- Electronic devices should be stopped during the transfers. Relevant “fire containment battery bags” should also be transferred with the devices.
- Some models of cell phones are designed to be water-resistant (1 to 2 m depth maximum). They should be opened to allow for equalization and avoiding damage. Note that the study of likelihood discussed previously shows that fires often start with damaged devices.
- QinetiQ report recommends limiting the compression and decompression rates but does not provide any value. Thus, the reduction of the compression/decompression speeds is currently at the LSS discretion. Nevertheless, although no official rule is published, no incident has been officially reported for the moment.

6.7 - Last precautions before entering the chamber

It is important to ensure that everyone understand and adhere to the rules discussed above.

- A tool-box talk must be organized to discuss the consequences of a fire in the chamber, the conditions that can trigger the thermal runaway of a lithium cell, and the reasons for the rules described above.
- The Life Support supervisor must ensure the conformity of the cell phones, tablets, and laptops planned to be transferred to the chamber with the list previously established. He must also ensure that no forbidden device is transferred in the chamber with the divers' belonging (including USB cords).

7 - Conclusion

It is impossible to publish permanent rules regarding the problems arising from battery-powered portable electronic apparatus because the products proposed by the manufacturers evolve and are quickly obsolete. Thus the problems posed by some devices can be quickly solved, but other issues can also happen.

Regarding the policy a diving company can select for electronic devices in hyperbaric chambers, we can see that other solutions than merely forbidding these apparatus can be selected. The best example comes from air transporters organizations such as the International Air Transport Association (IATA) that actively support new technologies for controlling fires and explosions resulting from the potential thermal runaways of these devices. The “fire containment bags” and high-temperature gloves described in the previous points result from these actions.

Based on the facts indicated above, even though the QinetiQ report and this evaluation say that using lithium-ion battery-powered apparatuses and other small electrical and electronic devices is possible in chambers as long as relevant control measures are in place, the diving team must prove that this problem is properly managed. For this reason, a risk assessment that considers recent incident records, the newly available control measures, and the apparatuses planned in the chambers must be done before starting the diving project.