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# Guidelines for reducing the environmental impact of general anaesthesia§,§§

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**Keywords:**

Guidelines Sustainable development Operating room Environmental impact Anaesthetic gas Intravenous drugs Waste

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# ABSTRACT

## **Objective:**

To provide guidelines for reducing the environmental impact of general anaesthesia.

## **Design:**

A committee of ten experts from SFAR and SF2H and SFPC learned societies was set up. A policy of declaration of competing interests was applied and observed throughout the guideline-writing process. Likewise, it did not benefit from any funding from a company marketing a health product (drug or medical device). The committee followed the GRADE1 method (Grading of Recommendations Assessment, Development and Evaluation) to assess **the quality of the evidence on which the recommendations were based.**

## **Methods:**

We aimed to formulate recommendations according to the GRADE1 methodology for three different fields: anaesthesia vapours and gases; intravenous drugs; medical devices and the working environment. Each question was formulated according to the PICO format (Population, Intervention, Comparator, Outcome). The literature review and recommendations were formulated according to the GRADE1 methodology.

## **Results:**

The experts' work on the synthesis and application of the GRADE1 method led to the formulation of 17 recommendations. Since the GRADE1 method could not be entirely applied to all of the questions, some of the recommendations were formulated as expert opinions.

## **Conclusion:**

Based on strong agreement between experts, we produced 17 recommendations designed to guide reducing the environmental impact of general anaesthesia. \_C 2023 Société française d'anesthésie et de réanimation (Sfar).

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# Introduction

For intensive care anaesthetists, the reduction of the environmental impact of general anaesthesia has become a legal and humanitarian preoccupation in the overall context of the fight against global warming.

Also known as anthropogenic global warming, climate change has been intensifying since the pre-industrial era (1850–1900) and has generated an ever-increasing volume of greenhouse gases (GHGs), including CO<sub>2</sub>, trapping heat in the atmosphere and warming the planet. Since the 1850's, global temperature has risen by 1.8, and it is currently rising by 0.2 °C per decade [1–3]. Health-related consequences consist of increased human morbidity and mortality with more and more heat waves and cold spells, flooding, drought, infectious diseases, and altered quality of air and water [4]. Every year, approximately 150,000 deaths can be attributed to global warming, and by 2030, the number of violent events is likely to have doubled [5]. A 2014 United Nations report estimated that by 2030, excessive mortality due to global warming will have reached 230,000 persons a year. In 2022, in a published report on the present-day evolution of global warming, the intergovernmental panel on climate change (IPCC) came to the conclusion that in order to limit global warming to 1.5°C, it will be necessary that within fewer than ten years, we drastically change our habits in view of reducing our GHG emissions [6]. Concretely speaking, to attain the objective of net-zero emissions by 2050, between 2010 and 2030 GHG emissions must be reduced by at least 45%.

Worldwide healthcare systems are responsible for 5.5%–8% of GHG emissions [7]. In terms of the quantity of GHG emissions, France as a country and its healthcare system are ranked 5th, and GHG emissions emanating from its healthcare system represent an estimated 4.6%–8% of the country's overall emissions. Healthcare centres are now subject to the legal obligation to carry out a carbon footprint report and to implement policies designed to reduce their environmental impact, the main sources of GHG emission are energy consumption (electricity, heating, . . .), freight delivery, medical gases (including nitrous oxide and halogenated vapours) and waste management. That said, the environmental impact of the healthcare system is by no means limited to GHGs. There also exist other indicators such as fine-particle emissions, atmospheric pollutants (nitrogen oxide, sulfur dioxide) and the ecotoxicity of drugs with regard to water and soil, which notably involves the molecules routinely used in anaesthesia–intensive care departments, generating a high rate of wastage [8].

Faced with these new challenges that must be addressed by healthcare establishments and professionals, the Société Française d'Anesthésie et de Réanimation (SFAR) in collaboration with the Société Française d'Hygiène Hospitalière (SF2H) and the Société Française de Pharmacie Clinique (SFPC) have come together to draw up a reference document on reduction of the environmental impact of general anaesthesia in the operating theatre.

## **Objective of the recommendations**

The objective of these recommendations is to provide intensive care anaesthetists with data on the environmental impact of different general anaesthesia strategies so that this dimension be part and parcel of the multiple arguments they take into account when deciding on the best anaesthesia strategy to be applied on a given day for a given patient. We wish to create a framework that will facilitate routine decision-making in view of reducing the environmental impact of general anaesthesia.

The objective of these guidelines is not to recommend an anaesthesia strategy on the basis of solely environmental arguments that would be decoupled from the clinical data (pharmacodynamic, prognostic. . .) already at the disposal of either the general population or specific sub-populations.

The group of experts has put together a limited number of recommendations, it is in view of highlighting the major points, which have been grouped into three predefined fields: anaesthetic vapours and gases; intravenous drugs; and medical devices and workplace environment. The targeted public is broad-based, encompassing all the medical and paramedical professionals involved in the practice of anaesthesia and intensive care.

## **Methodology**

### **General organization**

These recommendations result from the work of a group of experts brought together by the SFAR, the SFPC and the SF2H. Prior to analysis, each expert filled out a declaration concerning possible competing interests. As a first step, the organizing committee defined the objectives, the methodology, the field of application and the questions to be addressed in the recommendations. These elements were subsequently modified and validated by the experts.

To the greatest possible extent, the questions were formulated in accordance with the PICO format (Population – Intervention – Comparison – Outcome). The population to whom these guidelines are addressed (the ‘‘P’’ in PICO) is composed of the anaesthesia-intensive care staff practising in the operating theatre (this is not repeated for each of the recommendations).

### **The recommendation fields**

For the present recommendations, the experts unanimously decided to focus on the three following fields:

FIELD 1 — anaesthetic vapours and gases

FIELD 2 — intravenous drugs

FIELD 3 — medical devices and workplace environment

These three fields were chosen due to their homogeneity in terms of environmental impact during general anaesthesia.

Up until March 2022, extensive bibliographic research was carried out on the MEDLINE and [www.clinicaltrials.gov](http://www.clinicaltrials.gov) databases by at least two experts for each field of application in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology for systematic reviews.

Included in the analysis: meta-analyses, randomized controlled trials, non-randomized prospective trials, retrospective cohorts, series of cases and case reports, and scientific studies (in the fields of climatology, chemistry and physics) conducted among patients and caregivers (or in their environment), and dealing with the environmental impact of procedures related to general anaesthesia, published in English or French.

Analysis of the literature was then carried out in accordance with the GRADE1 (Grade of Recommendation Assessment, Development and Evaluation) methodology. The endpoints were preliminarily defined as follows:

- Primary endpoint: environmental impact (importance 7);
- Secondary endpoint: comfort and usability for the patient (importance 6) and comfort and usability for the caregiver (importance 4).

Given the very low number of studies presenting sufficient power with regard to the primary endpoint (i.e. environmental impact), it was decided before the recommendations were drafted to adopt a “Recommendations for Professional Practice” (RPP) rather than a Formalized Expert Recommendations (FER) format. That said, the GRADE1 methodology was applied in the analysis of the literature and in the drafting of summary tables recapitulating the data in the literature. A level of evidence was determined for each of the cited bibliographic references according to the type of study. It could subsequently be reevaluated according to the methodological quality of the study, the consistency of the results between the different studies, the direct or indirect nature of the evidence, and the analysis of the cost and extent of benefit. The recommendations were then written out, using the SFAR terminology for RPP: “the experts suggest to do” or “the experts suggest not to do”. After this, the proposals for recommendations were presented to the experts and discussed, one by one. The goal was not necessarily to arrive at a single and convergent opinion on all the proposals, but rather to distinguish points of agreement from points of divergence or indecision.

Each recommendation was independently assessed by each expert and individually rated on a scale ranging from 1 (complete disagreement) to 9 (complete agreement). The collective rating was validated by the experts according to the GRADE1 grid methodology. In order to validate a given recommendation, at least 70% of the experts had to express a generally convergent opinion, while fewer than 20% expressed a divergent opinion. If one or more recommendations were not validated, they were reformulated, after which they were rated again, the objective being to reach a consensus.



# Results

## Recommendation fields

During the first recommendations for professional practice (RPP) organizing meeting, the experts consensually decided to address eleven questions in three fields. The following questions were chosen for the collection and analysis of the literature:

### **FIELD 1 — anaesthetic vapours and gases Questions:**

- \* Does general anaesthesia by sevoflurane inhalation more effectively help to reduce environmental impact than anaesthesia by desflurane or isoflurane inhalation?
- \* Does general anaesthesia inhaled without nitrous oxide more effectively help to reduce environmental impact than anaesthesia inhaled with nitrous oxide?
- \* Does reduced fresh gas flow during inhalational general anaesthesia more effectively help to reduce environmental impact than inhalational general anaesthesia with high fresh gas flow?
- \* Does utilization of anaesthetic gas recapture systems during inhalational general anaesthesia more effectively help to reduce environmental impact than inhalational anaesthesia with the elimination of gaseous and liquid effluents through anaesthetic gas scavenging systems (AGSS)?
- \* Does monitoring the depth of anaesthesia in addition to monitoring of end-tidal anaesthetic concentration during inhalational anaesthesia more effectively help to reduce environmental impact than inhalational anaesthesia utilizing the latter form of monitoring alone?
- \* Does total intravenous anaesthesia more effectively help to reduce environmental impact than inhalational general anaesthesia maintained by halogenated vapours?

### **FIELD 2 — intravenous drugs Questions:**

- \* Does prior preparation of anaesthetic and emergency drugs more effectively help to reduce environmental impact than advance preparation, without compromising patient safety?
- \* Does monitoring of anaesthesia depth during total intravenous general anaesthesia more effectively help to reduce environmental impact than total intravenous general anaesthesia without monitoring of anaesthesia depth?

### **FIELD 3 — medical devices and workplace environment**

#### **Questions:**

- \* Does the use of reusable medical devices (medication trays, facial masks, respirator circuits, laryngoscope blades. . .) help to reduce environmental impact compared to single-use medical devices, **without compromising patient safety?**

\* Does a weekly change of respirator/anaesthesia circuits help to reduce environmental impact compared to daily change, without compromising patient safety?

\* Do waste sorting, recycling and waste reclamation policies in anaesthesia and intensive care units help to reduce environmental impact, without compromising patient safety?

### **Synthesis of the results**

Following a synthesis of the experts' work and application of the GRADE1 method, 17 recommendations were formalized. All of these recommendations were submitted for assessment, using the GRADE1 Grid method. After two rounds of rating, a strong agreement was reached for 100% of the recommendations.

The present PPRs replace the preceding SFAR guidelines for the same fields of application. The SFAR strongly urges all anaesthetists and intensivists to take into consideration the environmental dimension in the different arguments with which they are confronted, the objective always being to ensure the best patient care. However, when applying these recommendations, each practitioner is called upon to exercise his own judgment, taking into full account the specificities of one's establishment, so as to decide on the means of intervention best suited to the state of the patient of whom one is in charge.

### **FIELD 1: anaesthetic vapours and gases**

#### **Question:**

**Does general anaesthesia by sevoflurane inhalation more effectively help to reduce environmental impact than anaesthesia by desflurane or isoflurane?**

#### Experts:

Jérémie Garnier (Amiens); Jean-Claude Pauchard (Biarritz); Laure Bonnet (Monaco); Valérie Sautou (Clermont- Ferrand).

**R1.1 — The experts suggest, with equal clinical benefit for the patient, that in their choice of an inhalational anaesthetic, anaesthesia professionals prefer sevoflurane to desflurane or isoflurane, the objective being to reduce the environmental impact of general anaesthesia. EXPERT OPINION (STRONG AGREEMENT)**

### **Argumentation**

#### **The environmental data**

All of the halogenated gases belong to the class of fluorocarbons, and they are classified as greenhouse gases (GHG), whose power of contribution to global warming is measured in terms of global warming potential over 100 years (GWP100) compared to the reference gas, CO<sub>2</sub>, of which GWP100 is equal to 1. The physicochemical properties of these gases impart them with global warming power insofar as they possess the three characteristics of

greenhouse gases [9]: a relatively long atmospheric lifetime; sizable infrared absorption during their entire lifetime; and an infrared absorption spectrum situated in the “atmospheric window”, the spectral region in the infrared emission spectrum of the earth where the absorption of natural greenhouse gases (H<sub>2</sub>O, CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) is relatively weak [10]. For desflurane, the atmospheric lifetime is 14 years, and its GWP<sub>100</sub> is equal to 2540; for isoflurane, its atmospheric lifetime is 3.2 years and its GWP<sub>100</sub> is equal to 510; as for sevoflurane, its atmospheric lifetime is 1.1 years, and its GWP<sub>100</sub> is equal to “only” 130 [11–14]. Moreover, some halogenic gases possess a bromine atom or a chlorine atom, as well as ozone depletion potential (ODP) [15]. Isoflurane as well as halothane are Chlorofluorocarbons (CFC). Compared to Trichlorofluoromethane (CFC-11), their respective ODPs are 0.01 (isoflurane) and 0.4 halothane [10].

When they are utilised during general anaesthesia, the metabolism of these vapours is very weak: 5% (sevoflurane), 0.2%–0.5% (isoflurane) and 0.05% (desflurane) [16]. As a result, virtually all of the halogenated vapours are expired by the patient in an unchanged form and directly discharged into the atmosphere via the anaesthetic gas scavenging systems (AGSS) with which some rooms are equipped. Of note, for several years the atmospheric concentration of the different halogenated gases, especially and most constantly desflurane, has been on the upswing. Out of the 3.1 – 0.6 million tons of CO<sub>2</sub> equivalent (eqCO<sub>2</sub>) inherent to the release in the atmosphere of halogenated gases, 80% are due to desflurane [17]. GHG emissions during desflurane’s life cycle are 20 times higher than those of sevoflurane and 15 times higher than those of isoflurane [18]. When desflurane was not part of the therapeutic arsenal, GHG emissions due to anaesthetics inhaled in operating rooms were one-tenth [19,20]. As regards surgical interventions, a 25% reduction of GHG emissions has been observed, when sevoflurane is preferred to desflurane [21]. Lastly, when comparing the carbon footprint equivalent of an hour of anaesthesia to fresh gas flow at 1 L/min, with a target of 1 MAC/h, sevoflurane utilization is equivalent to driving a car for 6.5 km, isoflurane for 13 km and desflurane for 300 km (North American car 200 g eqCO<sub>2</sub>/ km) [22].

#### **Question:**

**Does general anaesthesia inhaled without nitrous oxide more effectively help to reduce the environmental impact than anaesthesia inhaled with nitrous oxide?**

#### **Experts:**

Valérie Sautou (Clermont Ferrand); Je´re´mie Garnier (Amiens); Laure BONNET (Monaco).

**R1.2.1 — The experts suggest, with equal clinical benefit for the patient, that when choosing an inhalational anaesthetic, anaesthesia professionals not utilise nitrous oxide, the objective being to reduce the environmental impact of general anaesthesia.**

#### **EXPERT OPINION (STRONG AGREEMENT)**

**R1.2.2 – The experts suggest that when nitrous oxide use is nonetheless used as an inhalational anaesthetic, one alternative can be to have it delivered in a bottle rather**

**than a canister and delivery circuit, the objective being to reduce the environmental impact of general anaesthesia.**

## **EXPERT OPINION (STRONG AGREEMENT)**

### **Argumentation**

#### **The environmental data**

Nitrous oxide is a GHG (N<sub>2</sub>O) with a very strong impact on global warming due to GWP100 equal to 265 and an atmospheric lifetime of 114 years [23]; moreover, it is highly responsible for ozone depletion [24]. N<sub>2</sub>O in anaesthesia represents an estimated 1%–3% of worldwide N<sub>2</sub>O emissions [13,25], which is considered appreciable due not only to the marked environmental impact of N<sub>2</sub>O but also to its capacity to aggravate the environmental impact of the other anaesthetic gases with which it is associated. More precisely, the use of N<sub>2</sub>O as carrier gas increases the environmental impact of sevoflurane and isoflurane; their values of CDE<sub>20</sub> and CDE<sub>100</sub> (carbon dioxide equivalents over 20 and 100 years) are multiplied by factors of 6 and 3 respectively when the carrier gas is a N<sub>2</sub>O/O<sub>2</sub> mixture, versus O<sub>2</sub>/air [12]. When associated with reduced fresh gas flow, the elimination of N<sub>2</sub>O in anaesthetic gas mixtures can lead to GHG emission reduction potentially as high as a factor of 20 for utilization of one MAC/ hour [18]. Numerous authors have highlighted the environmental impact of N<sub>2</sub>O, and most have urged anaesthetists to review their practices in view of reducing and even eliminating its use [22,26–29]. It is also important to note that operating theatres are supplied with N<sub>2</sub>O through channels and by means of canisters (networks of compressed cylinders) containing the gas in liquid form. Unfortunately, it has been demonstrated that, due to difficulties in detecting and maintaining the networks, channel leakage is difficult to avoid. Segleniek et al. underlined the substantiality of the leakage (more than 75% of actual consumption in their hospital) by quantifying the gap between the quantities consumed in the operating theatre and those measured in the canisters [30]. In an 8-room surgical unit, the quantity of N<sub>2</sub>O dilapidated by leakage throughout the transmission circuit represented 38,400 h of anaesthesia with 3% sevoflurane or 600,000 km of automobile travel. Aside from pollution, this abusive consumption of anaesthetic gas has an economic impact [30].

#### **The clinical data**

Given the incontestable unsuitability of N<sub>2</sub>O according to environmental criteria, the clinical interest of this gas has been called into question. N<sub>2</sub>O possesses low anaesthetic potency and can consequently not be used alone for general anaesthesia. It is necessarily associated with other halogenated gases, of which it reduces consumption with an equivalent effect. Its high diffusivity and low lipid solubility explain its rapidity of action in pulmonary delivery [31]. When secondarily added to a gas mixture containing a halogenated agent, it contributes to a “second gas” effect, as it is diffused more rapidly from the alveolar compartment to the blood compartment and accelerates the speed of induction and degradation of the halogenated agent when the patient awakens. However, these effects are limited by less lipid-soluble gases such as desflurane and sevoflurane. Well-managed administration of the halogenic agents and

fresh gas flows during induction and awakening can limit the above-mentioned drawbacks [32]. In paediatrics, N<sub>2</sub>O use is largely explained by the rapidity of inhalation induction. That said, N<sub>2</sub>O does not function effectively immediately after mask installation, and other, generally effective means of distraction are essential [32]. Despite N<sub>2</sub>O's antihyperalgesic effects due to its anti-NMDA action, which helps to reduce perioperative and postoperative central sensitization phenomena, it can be replaced by other molecules having the same anti-NMDA effects, one example being ketamine [33]. In addition, N<sub>2</sub>O is not without adverse effects; nausea and vomiting are particularly frequent with N<sub>2</sub>O anaesthesia [34]. Its high diffusivity provides it with access to closed cavities in as few as 30 min, which means that its use is ill-advised during prolonged gastrointestinal surgery [35]. All in all, N<sub>2</sub>O does not seem to present a major benefit during general anaesthesia, and it would appear quite possible to stop utilizing its delivery networks in the operating theatre. In the specific framework of paediatrics, Equimolar Mixture of Oxygen and Nitrous Oxide (EMONO) bottles could be envisioned. In any case, if an establishment decides to stop using nitrous oxide, it is important to not simply close the circuit in the operating theatre, but also to remove the canisters so as to avoid leakage leading to continued "consumption" of nitrous oxide.

#### **Question:**

**Does reduced fresh gas flow during inhalational general anaesthesia more effectively reduce environmental impact than inhalational anaesthesia with high fresh gas flow?**

#### **Experts:**

Laure Bonnet (Monaco); Jérémie Garnier (Amiens); Valérie Sautou (Clermont Ferrand); Jean-Claude Pauchard (Biarritz)

**R1.3.1 — The experts suggest that during inhalational anaesthesia, in view of reducing the environmental impact, anaesthesia professionals privilege low fresh gas flow. EXPERT OPINION (STRONG AGREEMENT)**

**R1.3.2 — The experts suggest that anaesthesia professionals equipped with a target-controlled infusion (TCI) system should prefer automatic to manual delivery, the objective being to reduce fresh gas flow and the environmental impact of general anaesthesia.**

**EXPERT OPINION (STRONG AGREEMENT)**

#### **Argumentation**

##### **The environmental data**

There is growing contemporary interest in the economic costs of climate change, otherwise known as the social costs of carbon (SCC), and these considerations can help to assess the economic advantages of different climate change policies. The social costs of carbon are generally estimated as the net present-day value of the impacts of climate change over the next 100 years (or more) of an additional ton of carbon emitted in the atmosphere at this time.

The SCCs attributable to anaesthetic gases can be as many as 12 times higher for desflurane than for isoflurane, depending on the rate of fresh gas flow (FGF). As much as the choice of anaesthetic agent, FGF has a direct effect on climate change and its worldwide economic repercussions [12].

Reduced FGF decreases the pollution associated with halogenated agents by reducing GHG emissions. When FGF is reduced, the CDE20 (carbon equivalent over 20 years) of desflurane decreases from 26.8 with FGF at 2 L/min to 6.7 with FGF at 0.5 L/min [12]. The environmental impact of desflurane with FGF at 1 L/min is 13 times greater than sevoflurane with FGF at 2 L/min [36]. Whatever the means of FGF management (manual or automatic), reduced FGF leads to reduced consumption of inhaled agents; this has been demonstrated by means of manual FGF regulation [37–39]. As regards TCI (target-controlled infusion), it leads to more markedly reduced consumption than manual delivery (estimated at 65% for desflurane). In addition, it leads to a close to 40% reduction of CO<sub>2</sub> emissions, more precisely targeted anaesthesia and decreased anaesthesia team workload, possibly leading to permanent LFGF use [40–43]. Several studies evaluating the consumption of halogenated gases have also assessed the financial impact, and unsurprisingly, it has been convincingly shown that lower consumption entails substantial cost reductions [37,39,42–44]. This argument should be emphasized, insofar as it can carry considerable weight when negotiating the purchase of TGI-equipped ventilators. That said, overconsumption of soda lime during TGI use may generate additional waste of which the economic impact has yet to be determined, as no analysis of the soda lime life cycle is presently available [45]. That said, the costs associated with increased soda lime consumption could be an estimated two to four times greater than costs without it [46].

### **The clinical data**

Classification of fresh gas flow rates is derived from the work by Simonescu in 1986 that was updated by Baker [47], who defined low fresh gas flow anaesthesia (LFGF) as flow between 0.5 and 1 L/min. A key risk of LFGF utilization consists of a weakened mixture with oxygen, potentially leading to desaturation and hypoxia. The emergence and subsequent diffusion of diversified means of monitoring (gas analysers, oxygen saturation monitoring, adjusted alarm levels. . .) have helped to minimize this risk and popularize LFGF use [27,37,48,49]. Another risk consists in the formation of compound A (pentafluoroisopropanol-fluoromethyl ether), which corresponds to the degradation product of sevoflurane in contact with the strong bases contained in soda lime (sodium hydroxide or potassium hydroxide), of which the production depends on sevoflurane concentration, temperature and soda lime hydration [36]. When FGF is reduced, the concentration of the sevoflurane in contact with soda lime increases, and degradation subsequently increases. As a result, when the FGF level is low, the risk of compound A production is heightened. Compound A nephrotoxicity has been demonstrated in rodents [50]. The Food and Drug Administration has limited the use of sevoflurane with FGF >2 L/min and, by application of the precautionary principle, 1 MAC/2 h must not be exceeded. However, the renal toxicity of compound A has not been proven in humans [46,51,52]. New and more expensive forms of soda lime now

exist; since they do not produce compound A, the preceding problem is totally resolved [40]. Safe practice of low fresh gas flow is now possible.

**Question:**

**Does utilization of anaesthetic gas recapture systems during inhalational general anaesthesia more effectively reduce the environmental impact than inhalational anaesthesia with the elimination of gas and liquid effluents using anaesthetic gas scavenging systems (AGSS)?**

**Experts:**

Jean-Claude Pauchard (Biarritz); El Mahdi Hafiani (Paris)

**Absence of recommendation. As of now, the data in the literature do not permit comparison of anaesthetic gas recapture systems with anaesthetic gas scavenging systems from either a patient and caregiver safety angle or from an environmental standpoint.**

**Argumentation**

As regards pollution by anaesthetic vapours in operating theatres, no regulatory standard exists. That said, the analysis of the 10 October 1985 circular from the French health ministry [53], which was based on the recommendations put forward by the national anaesthesia commission, stipulates that anaesthesia rooms must be equipped with devices ensuring the evacuation of anaesthetic gases and vapours, and that “these devices must permit, during the maintenance phase of anaesthesia and in the proximity of patient and staff, to lower concentrations to 25 ppm (nitrous oxide) and less than 2 ppm (halogenic agents)”. As for the WHO specifications, they recommend air exchange at 15 vol/h for operating theatres. A guide edited by CRAMIF/CPAM in 1996 on the prevention of professional exposure to anaesthetic gases and vapours [54] indicates that to avoid exposure, the air exchange rate must be between 15 and 25 vol/h. As a preventive measure, all properly equipped operating theatres must contain general ventilation systems allowing an air exchange throughout the premises.

In anaesthesia areas, the SFAR recommends [55] the utilisation of antipollution systems that evacuate from the building the nitrous oxide and halogenated vapours discharged from the outlet valves of the anaesthesia system and the ventilator. The absorbent canisters retain halogenated vapours, but not nitrous oxide. As regards the anaesthetic gas scavenging system (AGSS), which neither treats nor filters, it vents out the polluting vapours via the Venturi effect, directly connected to the air network (flow from 40 to 60 L/min) and transfers the pollution and toxicity of the anaesthetic gases from inside to outside the building. Moreover, a vacuum may be connected to an AGSS interface, and its functioning will consequently entail energy costs.

## **Question:**

**Does monitoring the depth of anaesthesia in addition to monitoring of end-tidal anaesthetic concentration during inhalational general anaesthesia more effectively help to reduce environmental impact than inhalational anaesthesia utilizing the latter form of monitoring alone?**

## **Experts:**

Stéphanie Pons (Paris); El Mahdi Hafiani (Paris)

**R1.4 — The experts suggest that during inhalational anaesthesia, anaesthesia professionals monitor the depth of anaesthesia in association with end-tidal anaesthetic concentration, the objective being to reduce the consumption of anaesthetic vapours as well as the environmental impact of general anaesthesia.**

**Avis d'experts (Accord fort)**

## **Argumentation**

### **The environmental data**

To our knowledge, no study has directly assessed the environmental impact of the monitoring of depth of anaesthesia during inhalational general anaesthesia, which may nevertheless be indirectly evaluated through studies on the effect of monitoring on the consumption of halogenated vapours.

Several studies of which the primary endpoint is halogen consumption have found that it decreases when the depth of anaesthesia is monitored [56–59], whereas others have not found any difference [60–62], while four studies evaluating this parameter as a secondary endpoint have reported a reduced halogen consumption with monitoring [63–66], and three others have found no difference [67–69]. The meta-analysis by Liu et al., which included 1380 patients from 11 studies, reported a 19% reduction in consumption of inhaled and intravenous anaesthetics when bispectral (BIS) index monitoring was used [70]. By the same token, the meta-analysis carried out by Punjasawadong et al. highlighted a reduced consumption of anaesthetic gases during BIS monitoring, but heterogeneous control groups were included, based on either clinical signs or end-tidal anaesthetic concentration [71]. In yet another meta-analysis, it was shown that spectral entropy monitoring significantly reduced sevoflurane consumption [72]. To conclude, there exists a trend in favour of reduced consumption of halogenated vapours through the monitoring of depth of anaesthesia during inhalational anaesthesia; which logically entails reduction of the GHG emissions inherent to halogenated vapours and diminution of their environmental impact.

### **The clinical data**

A study of the clinical benefits of monitoring the depth of anaesthesia during general anaesthesia maintained by anaesthetic vapours is markedly heterogeneous, particularly as regards the parameters to be assessed. As regards the occurrence of perioperative



memorization, in an initial analysis bispectral index monitoring (BIS) did not lead to a reduction of memorizations during isoflurane inhalation [73]. By the same token, no difference in the incidence of perioperative memorization was found between the groups of patients monitored by BIS and those monitored by end-tidal anaesthetic concentration alone. However, another meta-analysis showed that while, in comparison with standard clinical surveillance, BIS monitoring could reduce the risk of memorization occurrence, this benefit was not confirmed during monitoring with audible alarms of end-tidal anaesthetic concentration fraction [74]. The American Society for Enhanced Recovery and Perioperative Quality has issued recommendations for the use of either one method or the other to prevent memorization risk during inhalational general anaesthesia [74]. As regards a possibly reduced time interval before eye-opening and extubation when the depth of anaesthesia is being monitored, the literature is divergent; while some studies are positive [63,67], others are negative [60,61,65]. One meta-analysis demonstrated that the time interval before the opening of the eyes was significantly lower during BIS monitoring in patients anaesthetized with sevoflurane or isoflurane, but not desflurane [73]. In these studies, however, the time intervals were reduced by only two to six minutes. In ambulatory surgery, BIS monitoring has been shown to reduce the risk of postoperative nausea and vomiting, as well as time spent in a post-anaesthesia care unit [70,75], whereas other studies on ambulatory and conventional surgery have contested these results [56,60,64]. As regards the impact of anaesthesia depth monitoring on occurrence of postoperative delirium, study results are likewise discordant. That said, the European Society of Anesthesiology guidelines recommend its being used, if available, in all patients at high or low risk of postoperative delirium [76]. The SFAR also recommends anaesthesia depth monitoring in elderly patients, the objectives being to prevent postoperative delirium and anaesthetic overdose [77]. However, following a large-scale randomized trial, Wildes et al. did not demonstrate the preferability of this type of monitoring to standard clinical surveillance during inhalational anaesthesia [78]. The authors nevertheless observed a diminution of 30-day mortality in the “depth-monitored” group, which may have been secondary to lessened incidence of perioperative cardiovascular instability. This reduction of medium-term morbi-mortality in patients having been monitored by bispectral index was previously observed in other studies [79].

A legitimate question is: given the price of the electrodes used to monitor the depth of anaesthesia, can this approach be cost-effective? While some studies show that savings from non-use of halogenated agents fail to offset the price of the electrodes [58,60], the randomized study by Bocskai et al. [60] and a systematic review of the medico-economic literature show that monitoring by BIS or entropy indeed leads to reduced costs, given that the savings achieved through non-use of halogenated agents exceed the cost of monitoring.

#### **Question:**

**Does total intravenous general anaesthesia more effectively help to reduce environmental impact than inhalational general anaesthesia maintained by halogenated vapours?**

## **Experts:**

Jean-Claude Pauchard (Biarritz); Delphine Cabel-guenne (Lyon)

**R1.5 — From the standpoint of environmental impact, the experts suggest that, with equal clinical benefit for the patient, anaesthesia professionals utilize either maintained general anaesthesia by inhaled vapours, or total intravenous general anaesthesia by propofol injection; while the former have an environmental impact through greenhouse gas emission, the latter are ecotoxic for water and soils.**

## **EXPERT ADVICE (STRONG AGREEMENT)**

### **Argumentation**

#### **The environmental data**

As GHGs, halogenated vapours contribute to anthropic global warming. Not having been metabolized, approximately 98% of these gases are practically integrally released into the atmosphere. As a result, the worldwide carbon cost of halogenated vapours is estimated at about 3.1 million  $\pm$  0.6 tons EqCO<sub>2</sub> [17], representing 5% of the carbon footprint in the hospital sector [27] and the largest carbon footprint component in the operating theatre [19,80]. Associated with nitrous oxide, halogenated vapours account for 42% of the carbon emissions generated during surgical interventions [81]. The ecological impact of halogenated vapours could nonetheless be reduced by gas recapture or scavenging systems [82].

Even though, and by definition, intravenous induction agents are not greenhouse gases, they are indeed polluters of soils and water. Some of these agents are not even utilised before being discarded (from 14% to 49%, according to the different authors, for propofol) [83–85]. As regards the part administered to the patient, 1% of the propofol is excreted in the urine in unchanged form and enters the biosphere, while the remaining 99% is metabolized, particularly by glucuronidation. As for the non-metabolized propofol, whether it is excreted by the patient or comes from wastage, it is highly toxic for aquatic organisms, generating long-term adverse effects. What is more, propofol presents a high potential for bioaccumulation and considerable mobility in soil, and it accumulates in fatty substances. Drawn up in Sweden, the PBT index (persistence, bioaccumulation and toxicity) classifies each drug molecule by risk of ecotoxicity; the scale ranges from 0 to 9, and the PBT index for propofol is 6 out of a possible 9 [86]. There exists no proof of its biodegradability in water, nor is it biodegradable under anaerobic conditions. To be completely destroyed, it must be incinerated at 1000 °C for at least two seconds [87]. Previous studies have shown that for environmental reasons, propofol is to be preferred to halogenated vapours [17,81]. However, the 2021 study by Hu et al., which compared inhalational anaesthesia with halogenated vapour to intravenous anaesthesia with propofol and took into account an approach to the assessment of the life cycle (LC) of the active pharmaceutical ingredient, showed that the respective carbon footprints of sevoflurane and propofol could be equivalent, using an oxygen/air mixture as carrier gas at the lowest flow rate (0.5 L/min), and employing technology aimed at recapturing and recycling 70% of the halogenated vapours (0.996 kg

CO<sub>2</sub> equivalent by MAC/h for sevoflurane anaesthesia vs. 1.013 kg of CO<sub>2</sub> equivalent by MAC/h for propofol anaesthesia) [88]. These results, in apparent contradiction with previous studies demonstrating a better carbon footprint with propofol, are the only ones to have incorporated the complete life cycle of this drug. None of the previous studies took into account the wasted plastics and other sharp objects (ex: needles) associated with the use of propofol, even if the carbon footprint due to these waste treatment operations is not nearly as high. However, none of these studies, including the one conducted by Hu et al., have taken into account a number of other environmental impacts, particularly the pronounced ecotoxicity of propofol, when it is not eliminated via a specific pathway [84]. As regards halogenated vapours, all of the non-metabolized gases are exhaled by patients and in the absence of gas recapture technology, they are diffused in the atmosphere, which is why they are included in calculations of carbon footprint. However, the materials constituting medical devices (tubes, circuits, CO<sub>2</sub> absorbers. . .) have been considered as equivalent for all halogenated vapours, and are consequently not included in the preceding calculations.

### **The clinical data**

As regards time before awakening, time of extubation, discharge from postoperative recovery room, postoperative delirium, mortality and length of hospital stay, there does not seem to exist any clinically significant difference between intravenous general anaesthesia by propofol and anaesthesia by halogenated vapours [89–95]. In comparison with total propofol-based general anaesthesia, anaesthesia by inhalation of halogenated vapours is associated with a doubled risk of early PONV, but without major specificity concerning the halogenating agent employed [96,97].

### **FIELD 2: intravenous drugs**

#### **Question:**

**Does extemporaneous preparation of anaesthetic and emergency drugs more effectively help to reduce environmental impact than advance preparation, without compromising patient safety?**

#### **Experts:**

Florence Lallement (Lille); Pierre Cassier (Lyon)

**R2.1.1 — With the exception of an expected or predicted emergency situation, the experts suggest that anaesthesia professionals prepare the medications only needed for the anaesthetic management of a given patient just before their use, rather than systematically preparing them beforehand, the objective being to reduce the environmental impact of general anaesthesia.**

#### **EXPERT OPINION (STRONG AGREEMENT)**

**R2.1.2 — The experts suggest that anaesthesia professionals utilize pre-filled syringes for occasionally used medicines, if suitably equipped, rather than preliminarily**

**preparing these medicines in classical syringes, the objective being to reduce the environmental impact of general anaesthesia.**

## **EXPERT OPINION (STRONG AGREEMENT)**

### **Argument**

A sizable number of anaesthetic drugs remain unused, and after each intervention or at the end of each day, they are thrown away. Studies have shown that from 20% to 50% of the medicines prepared are not utilized [98]. The discarded drugs differ in nature according to the type of intervention and the habits and preparation protocols of different units. In some study sites, unused propofol can represent up to 45% of waste material from medicinal products [87]. As regards emergency drugs, ephedrine, phenylephrine, atropine, adrenaline and suxamethonium chloride are the medicines most frequently thrown away without having been used [84,99]. Curares (immobilizing agents) belong to the list of drugs of major therapeutical interest (MTI) that are presently subject to supply difficulties and for which there is little or no therapeutical alternative available on the French market. The ANSM (French national agency for Medicines) monitors the management of these stock-outs, of which the accumulation illustrates a need for reinforced efforts to limit waste.

Unused drugs represent an avoidable financial and environmental cost. Propofol is a medicinal product contaminating the environment insofar as it is not biodegradable and accumulates rapidly, becoming toxic in aquatic settings [84,87]. Moreover, unused discarded syringes account for considerable yearly waste. On the contrary, reduced waste of medicinal products leads to lower healthcare costs and procures environmental benefits by preserving resources. In point of fact, financial and environmental benefits are frequently interwoven. To ensure patient safety, drugs must be at hand for immediate use in emergency situations. With this in mind, as an alternative to single-use vials prepared in advance, pre-filled syringes help to meet the need for emergency drugs. Even though the unit prices of pre-filled syringes are higher than those of preliminarily prepared syringes, the overall financial benefits are considerable [100,101]. A cost analysis incorporating preparation time was carried out for ephedrine and underlined its economic interest [102]. What is more, emergency drugs in the form of pre-filled syringes do not seem to have negative repercussions on the quality and safety of care. Drug dilution and preparation stability are more effectively ensured with pre-filled syringes than with those having been prepared in advance [84]. Studies on other emergency drugs still need to be conducted to confirm their benefits in terms of lessened or avoided waste. In certain establishments, some medicines are prepared by the central pharmacy; this type of preparation could be compared to the production of pre-filled syringes [84]. It also bears mentioning that in any attempt to reduce waste, habits in a given unit must be taken into account so as to devise solutions adapted to actual working conditions.

### **Question:**

**Does monitoring of anaesthesia depth during total intravenous general anaesthesia more effectively help to reduce environmental impact than total intravenous general anaesthesia without monitoring of anaesthesia depth?**

## **Experts:**

Stéphanie Pons (Paris); El Mahdi Hafiani (Paris)

**R2.2 — The experts suggest that during total intravenous general anaesthesia, anaesthetists monitor depth of anaesthesia in view of reducing consumption of anaesthetic drugs and, consequently, the environmental impact of general anaesthesia.**

### **EXPERT OPINION (STRONG AGREEMENT)**

#### Argumentation

The environmental data To our knowledge, up until now no study has directly assessed the environmental impact of anaesthesia depth monitoring during total intravenous anaesthesia. That said, the environmental impact could be indirectly evaluated through studies on how this monitoring affects the consumption of intravenous anaesthetic drugs. In many studies, a significant reduction of propofol consumption during total intravenous anaesthesia has been obtained through the performance of electro-encephalogram monitoring by bispectral index (BIS) or entropy [71,72,77,103– 110]; however, these results have not been confirmed in studies on ENT or orthopaedic surgery [60,111]. As regards morphine consumption, while the results differ from one study to another (with the exception of two articles [109,112]), they do not highlight significantly reduced consumption during anaesthesia depth monitoring [60,103,103,105–107]. All in all, the results indicate reduced propofol consumption during total intravenous anaesthesia, which would logically lead to reduced environmental toxicity due to propofol. On a parallel track, reduced consumption can be associated with financial savings [60], even if it remains uncertain whether the cost decrease due to lessened propofol consumption exceeds the price of a BIS electrode [75]. That said, if the costs generated by the complications ascribable to excessive or insufficient propofol dosage are taken into account, especially in the event of perioperative memorization, anaesthesia depth monitoring appears cost-effective [113].

#### **The clinical data**

Two recent meta-analyses have shown that in total intravenous anaesthesia, BIS monitoring leads to a significant reduction of perioperative memorization [73,74]. As a result, the American Society for Enhanced Recovery and Perioperative Quality has issued guidelines favouring anaesthesia depth monitoring during total intravenous anaesthesia in view of achieving this objective [74]. That said, studies on perioperative hemodynamic stability and patient awakening have yielded heterogeneous results. While some have demonstrated improved perioperative hemodynamic stability through anaesthesia depth monitoring [103,104], others have failed to provide confirmation [70,105]. In fact, while several studies have highlighted reduced extubation or awakening time with depth monitoring during total intravenous general anaesthesia [60,105,106], similar results have not been found in other publications [103,111,114], and in all of the cases, the time “saved” was minimal (a few minutes). As regards bispectral index monitoring for ambulatory surgery by total intravenous anaesthesia or inhalational anaesthesia, it has been shown to lead to significantly reduced risk

of postoperative nausea and vomiting, and time spent in post-anaesthesia recovery units [70,75,105]. During bronchial endoscopy procedures, it has been shown that the monitoring of depth of sedation by propofol/remifentanyl can reduce the number of desaturations and the frequency of adverse events [107]. However, these results have not been confirmed in digestive endoscopy [108]. In another surgical speciality, however, anaesthesia depth monitoring has been associated with lessened postoperative delirium in adult patients having undergone noncardiac surgery [71]. The European Society of Anaesthesiology guidelines call for its utilization, subject to availability, in all patients at low or high risk of postoperative delirium [76]. The SFAR likewise recommends anaesthesia depth monitoring in elderly patients, the objective being to prevent postoperative delirium and excessive doses of anaesthetics [77].

### **FIELD 3 — medical devices and workplace environment**

#### **Question:**

**Does the use of reusable medical devices (medication tray, facial masks, respirator circuit, laryngoscopy blade. . .) help to reduce environmental impact as compared to single-use medical devices, without compromising patient safety?**

#### **Experts:**

El Mahdi Hafiani (Paris); Laure Bonnet (Monaco); Delphine Cabelguenne (Lyon); Valérie Sautou (Clermont Ferrand).

**R3.1.1 — The experts suggest that anaesthesia professionals make maximum use of reusable rather than single-use medical devices, the objective being to reduce the environmental impact of general anaesthesia.**

#### **EXPERT OPINION (STRONG AGREEMENT)**

**R3.1.2 — The experts suggest when anaesthesia professionals utilize reusable medical devices, they develop procedures of inventory and operation ensuring that these devices be reutilized to the greatest possible extent, the objective being to reduce the environmental impact and financial cost of general anaesthesia.**

#### **EXPERT OPINION (STRONG AGREEMENT)**

**R3.1.3 — The experts suggest that as regards a given medical device, anaesthesia professionals avoid using a combination of single-use and reusable instruments, which would have additive rather than reductive effects on the environmental impact of general anaesthesia.**

#### **EXPERT OPINION (STRONG AGREEMENT)**

**R3.1.4 — The experts suggest that when anaesthesia professionals use plastic medical devices, they select models not containing diethylhexyl phthalate (DEHP) and that, in view of reducing the environmental impact of general anaesthesia, they avail themselves of the services of local manufacturers.**

#### **EXPERT OPINION (STRONG AGREEMENT)**

##### **Argumentation**

In addition to the traditional criteria for the selection and purchase of medical devices (safety, efficacy and cost), increasing awareness of the negative impacts of healthcare practices on the environment and public health has led to calls for systematic inclusion in product selection **processes of life-cycle criteria.**

##### **The environmental data**

To our knowledge, up until now no study has dealt with single vs. multiple use of monitoring cables and blood pressure cuffs in terms of environmental impact. As regards the blades and handles of laryngoscopes, during its life cycle a single-use handle generates 16–18 times more eqCO<sub>2</sub> than the usual low-level disinfection of a reusable steel handle [115]. In the same study, it was found that single-use plastic tongue blades generate five to six more times eqCO<sub>2</sub> than reusable steel blades treated with high-level disinfection. Moreover, single-use components in metal generate much higher emissions than all of the single-use or reusable alternatives in plastic. Other data have shown significantly reduced costs of reusable as compared to discardable devices [116,117]. For example, with regard to practically all the categories of pollution taken into consideration, reusable laryngeal masks (LM) have 50% fewer negative effects on the environment than discardable LMs [117]. The most pronounced difference has been observed in the category of carcinogenesis, in which reusable LMs have 95% less impact than discardable LMs. The deleterious impacts on human health and carcinogenesis of discardable masks are largely associated with the type of plastic and the presence of diethylhexyl phthalate (DEHP), which is a plasticizer routinely adjoined so as to provide PVC-based products (breathing tubes. . .) with flexibility. In addition to being a carcinogenic agent, DEHP is a potential endocrine disruptor [118]. It also bears mentioning that in terms of eutrophication (water pollution by organic wastes), the two types of LM are practically equivalent. Water consumption of a reusable mask (960 L for 40 utilizations) is higher than with 40 mL of a single-use mask. As for GHG emissions, over the course of its life cycle, a reusable LM produces 7.4 kg of eqCO<sub>2</sub>, while 40 LMs equivalent to 40 planned utilizations of a reusable LM produce 11.3 kg of eqCO<sub>2</sub>. In fact, the unit cost of discardable LMs is 20% higher than that of reusable LMs. In order to be environmentally and economically optimal, reusable LMs must be reused to their full capacity, which entails close monitoring of their use and, more specifically, of their sterilization cycles. To illustrate this point, for 20 cycles of reutilization of a reusable LM, GHG emissions and financial cost increase by 20 and 26% respectively, as compared to the recommended reutilization of 40 cycles [119]. Conversely, when the life cycle of a reusable LM is twice as long as (80 utilizations) as generally recommended by manufacturers, GHG emissions decrease by 9%, and the economic cost by 30% [120]. Manufacturers generally recommend no more than 40

utilisations per unit; however several studies have reported 100 and even 200 utilisations, without obvious complications [121,122].

In a model consisting of five configurations (respirator circuits, facial masks, LMs, laryngoscopes and video-laryngoscopes) of single- use and reusable anaesthesia material), McGain et al. demonstrated that the former always costs more than the latter [116]. In their study, most of the environmental impacts (eutrophication, solid wastes, human toxicity, ecotoxicity in land and sea. . .) associated with reusable equipment were less than those associated with single-use equipment; only eqCO<sub>2</sub> emissions and water consumption were superior. In this study, the conversion of single-use into reusable equipment increased eqCO<sub>2</sub> by close to 10%. That said, this effect is directly connected with the types of sources utilized to produce energy; in Australia, the site of the study by McGain et al., energy production is essentially based on coal. In Europe/Great Britain, on the other hand, where coal-free energy production has made strides, conversion of single-use into reusable articles would reduce eqCO<sub>2</sub> emissions by as much as 85 and 50% respectively. It bears mentioning that in this study, utilization of a combination or “mix” of single-use and reusable equipment led to more sizable eqCO<sub>2</sub> emissions than did utilization of either one or the other, the reason being that the environmental impact of single-use was compounded by the functioning of the washing material and the sterilizers required for treatment of reusable articles and devices. Lastly, in another model comparing the life cycles of single-use vs. reusable plastic anaesthetic drug trays, the authors showed that single-use drug trays were more costly, produced 15% eqCO<sub>2</sub> and consumed three times more water [123].

### **The clinical data**

Single-use medical devices in the operating theatre have a more pronounced environmental, financial and social impact than reusable devices [124]. As regards reusable blood pressure cuffs, while they are often contaminated by pathogenic agents due to insufficient disinfection [125,126], no causal link has been established between contamination and nosocomial infections. As regards the cables reused for ECG monitoring, results on the risk of surgical site infection are divergent [127,128]. The blades and handles of reusable laryngoscopes, which are often poorly cleaned and contaminated, may be implicated in some cases of cross-transmission of micro-organisms [120,129]. That said, up until now no study has compared reusable with discardable handles in terms of infection risks. Regarding laryngeal masks (LM), the general perception is that reusable LM possess a safety profile inferior to that of discardable LM. In point of fact, there exists a theoretical risk that protein substances (prion) adhere to reusable LMs, exposing patients to Creutzfeldt-Jakob disease transmissible spongiform encephalopathy [130]. Iatrogenic transmission of Creutzfeldt-Jakob has been observed worldwide in 250 patients, in six of whom it was associated with contaminated neurosurgical equipment. That said, all of these equipment-related cases occurred prior to systematic implementation of the sterilization procedures now applied in healthcare establishments, and no case of the aforementioned type has occurred since 1976; more broadly, no case whatsoever of iatrogenic infection connected with a reusable LM has occurred. Several clinical studies comparing the functioning and ease of LM insertion have not found any difference between the discardable and reusable versions [131–134].



## **Question:**

**Does weekly change of respirator circuits help to reduce environmental impact compared to daily change, without compromising patient safety?**

## **Experts:**

Stéphanie Pons (Paris); El Mahdi Hafiani (Paris)

**R3.2.1 — The experts suggest that in addition to changing the high-efficiency filter between each patient, anaesthesia professionals change the ventilatory circuit once a week rather than once a day, except in case of any visible soiling, the objective being to reduce the environmental impact of general anaesthesia.**

## **EXPERT OPINION (STRONG AGREEMENT)**

### **Argumentation**

The environmental data To our knowledge, up until now no study has directly assessed the environmental impact of changing an anaesthesia ventilatory circuit once a day rather than once a month. By the same token, an evaluation of the life cycle of a ventilatory circuit has not been specifically carried out. That said, the environmental impact of a less frequent change could be indirectly assessed in terms of the direct reduction of consumption by discardable anaesthetic circuits, and it would be interesting to appraise the life cycles of high-efficiency filters [85].

One study has dealt with the frequency of sterilization of reusable ventilatory circuits, and it was found in a hospital with six operating theatres that weekly rather than daily sterilization led to per year reduction of consumption by 2460 kW of electricity and 48,000 L of water [135].

From a financial standpoint, a per day rather than a per patient change of ventilatory circuit has been shown to lead to a reduction of expenses by as much as 40%, taking into account both equipment cost and waste management [136–138].

### **The clinical data**

In anaesthesia practice, reutilization of ventilatory circuits implies they are being utilised for several consecutive patients. The main risk when maintaining the circuit during several consecutive anaesthesia administrations is cross-contamination and the occurrence of infections, notably respiratory infections, during the postoperative period. Several studies have assessed the safety of ventilatory circuit maintenance over the course of several consecutive anaesthesia administrations; in most of them, systematic utilization and change from one patient to the next of the high-efficiency antibacterial and antiviral particulate air filter (HEPA) downstream from the Y-piece has allowed reutilization of the circuit for several patients, without its being bacterially contaminated [136,139]. Moreover, no systematically increased colonization of the ventilatory circuit has been demonstrated when it is changed every 24, 48 or 72 h, provided that a single-use antibacterial and antiviral filter has been

allotted to each patient [140]. In addition, no heightening of bacterial or viral contamination (for example, nosocomial viral infection due to cytomegalovirus, influenza or Parainfluenza virus, syncytial respiratory virus or Herpes simplex virus) in the ventilatory circuit has been observed when it is changed once a week rather than once a day, provided once again that a HEPA filter is used [141]. These findings have been confirmed in an Australian study comparing several frequencies of sterilization of reusable ventilatory circuits [135]; contamination did not increase when they were changed once a week rather than once a day. As a result, in 1997 the SFAR and in 2010 the German hospital hygiene society formulated guidelines recommending the adoption of weekly changing of the anaesthesia ventilatory circuit, provided that the high-efficiency antiviral and antibacterial filter is systematically used for one patient and changed for the next and that the manufacturers' guidelines are rigorously applied [138,142]. The circuit shall also have to be changed immediately, in the event of soiling, dysfunction or leakage. In addition, maintenance of the external surfaces of the pipes should be carried out between patients. To our knowledge, there exist no data in the literature on the safety of less frequent changing of ventilatory circuits.

**Question:**

**Do waste sorting, recycling and waste reclamation policies help to reduce environmental impact, without compromising patient safety?**

**Experts:**

Florence Lallement (Lille); Pierre Cassier (Lyon); Philippe Carencó (Hyères)

**R3.3.1 — The experts suggest that anaesthesia professionals set up waste sorting programs, the objective being to reduce the environmental impact of general anaesthesia.**

**EXPERT OPINION (STRONG AGREEMENT)**

**R3.3.2 – The experts suggest that anaesthesia professionals set up recycling and waste reclamation programs, the objectives being to reduce the environmental impact and cost of general anaesthesia.**

**EXPERT OPINION (STRONG AGREEMENT)**

**Argumentation**

Healthcare activities have a direct impact on the environment, which is due in particular to the waste products they generate [143]. Inappropriate waste sorting has a major financial and environmental cost, on account of expenses entailed by the elimination of non-recyclable infectious waste, the loss of discarded resources that could have been recycled, and the pollution potentially induced by the drugs. Sorting errors may be exceedingly numerous; one study reported 57%, and up to 70% for potentially recyclable waste products [74]. This issue is particularly important in operating theatres, which generate 30% of hospital waste products [144], a quarter of which are associated with anaesthesia [145]. While the waste products are

diversified in nature, packaging material predominates. Approximately 48% of wastes are produced during the preoperative phase.

Waste management encompasses the different means of reducing waste production, preserving resources and reducing the GHG emissions issued during their elimination. The first means of improvement consists of upgraded waste sorting (cf. Appendix A on the rules and regulations concerning waste products to be eliminated, whether or not they meet the IHCW – French “DASRI” – criteria). In one illustrative instance, a waste sorting program reduced the environmental impact in CO<sub>2</sub> equivalent by dint of a 43% decrease of infectious wastes and the ensuing increase of recycled material [146]. The second means of improvement consists of the enhanced promotion of recycling, which leads to reduced CO<sub>2</sub> emissions insofar as recycled materials are less energy-consuming and contribute to the preservation of natural resources [143]. Recycling and recovery of materials are essential to the reduction of the environmental impact of waste products (cf. Appendix B: Worksheet of the SFAR sustainable development committee on the sorting of operating theatre waste products in view of the description of recyclable waste products and their respective sectors). Several recycling sectors currently exist: paper, cartons, plastics (polypropylene, polyvinyl chloride) and metal (steel, aluminium) [147]. In several studies, a number of major obstacles to the recycling of operation room wastes have been pinpointed: inadequate knowledge and training in the treatment of recyclable products; problems of manipulation, space and ergonomics; inadequate labelling; and limited awareness of expected benefits [148–150]. While further works assessing the costs of recycling remain necessary, preliminary studies already suggest that it could be less expensive than waste elimination [143]. Potential financial benefits could be considered more in terms of costs avoided thanks to recycling rather than elimination, than in terms of the recovery and upgrading of recycled material [144], which presently approximates only 1% [74]. Other approaches are needed to stimulate adherence to waste sorting and recycling: thoroughgoing analysis of the life cycle of a product utilised before being recycled or discarded; study of the financial impact of recycling and waste product recovery.

In Appendix B, the SFAR worksheet on the sorting and valorisation of operating theatre waste products is designed to facilitate the reasoning and choices of healthcare staff in the sorting and management of operating theatre wastes.

### **Conflict of interest**

***All the authors declare that they do not have any link of interest related to these guidelines:***

Jean-Claude Pauchard does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

El-Madhi Hafiani does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

Laure Bonnet does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

Delphine Cabelguenne does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

Philippe Carenco does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

Pierre Cassier does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

Jérémie Garnier does not declare any conflict of interest that may be related to the work of the guidelines for reducing the environmental impact of general anesthesia.

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**Appendix A.**

***Synthesis of the rules and regulations on health care wastes (P. Carenco, E.M. Hafiani)***

According to article R1335-1 of the French public health code: Health care wastes are waste products derived from activities of diagnosis, follow-up and preventive or curative treatment, in the fields of human and veterinary medicine.

***Among these waste products, the following are subject to the provisions of the present section:***

1. Those presenting an infectious risk, due to their containing viable micro-organisms or their toxins, and about which it is known that there are good reasons to believe that on account of their nature, quantity or metabolism, they cause disease in humans or in other living organisms.
2. Those that, even in the absence of infectious risk, belong to one of the following categories:
  - a. **Sharp or cutting** materiel or materials meant to be discarded, whether or not they have been in contact with an organic product;
  - b. **Blood products** of therapeutic use that have been incompletely utilized or with no remaining shelf life (no laundry or compresses soiled with blood)
  - c. **Human anatomical waste**, corresponding to difficultly identifiable human fragments.

To conclude, no notion of soiling by blood or an organic liquid.

*As a result, two questions predominate:*

### **1. Which microorganisms cause disease?**

In all cases, the infectious agents causing highly severe infections are listed in class 4, according to article R4421-3 of the French labour code (Ebola, etc.).

For other micro-organisms, there are several interpretations of the texts which lead some establishments to consider all micro-organisms causing an infection in a patient as presenting an infectious risk; whereas elsewhere, only infectious agents causing serious infections (see above) will be considered at risk, excluding, for example, staphylococci and enterobacteria **which are frequently commensal in humans.**

### **2. Who determines their presence and how?**

In a care setting

- o The caregiver knows the care setting and the uses of a given device, for a given treatment and a given patient
- o As the producer, he is responsible for sorting the wastes he produces; he alone masters his choice
- o In a laboratory setting involving work on microorganisms! the different organic waste products

With these considerations in mind, the following waste products are to be eliminated in a disposable channel for infectious healthcare wastes (“DASRI” in French):

Waste products containing a micro-organism with pathogeny factor, and responsible for infection of a patient under treatment.

Some examples:

- \_ Bandage soaked with purulent fluid,
- \_ Puncture or suction liquid for viral or bacterial infection
- \_ Diaper containing diarrheal stools of infectious origin
- \_ Sharp-cutting material, even when not utilized
- \_ Blood product incompletely utilized or with no remaining shelf life
- \_ Unidentifiable bodily waste

**According to the rules and regulations, and given the definition of IHCW, the following products are not to be eliminated:**

- \_ Probes, tubing, syringes, diapers (**even if a patient is an MRB carrier**, as carriage is not a disease and there are many healthy **carriers** in the community (outside the health care system))
- \_ Medical equipment packaging
- \_ Urine bags, empty infusion and transfusion bags
- \_ Compresses and blood-soaked **surgical draping**, non-purulent bandages, gynecological protection

That said, application of the 2009 DGOS guide (updated in 2016) leads to a choice other than strict application of the above-mentioned rules and regulations: **“waste products to be systematically eliminated in a disposable channel for infectious healthcare wastes (IHCW/DASRI) due to its nature:** more generally, any care article or object soiled by (or containing) **blood** or another **organic fluid** (pleural, peritoneal, pericardial, amniotic, synovial fluid).

## **Appendix B.**

**Worksheet of the SFAR sustainable development committee: “The sorting of operating theatre and intensive care unit waste products” (E. d’Aranda, M. Paries, F. Lallemand, L. Bonnet)**

## DATA

Healthcare establishments, particularly operating theatres and intensive care units, are large-scale waste producers [84]. Waste product management is the responsibility of waste producers.

Healthcare waste (HCW) can present dangerous properties: infectious, radioactive, cytotoxic, chemical. . . Waste products without these dangerous properties are known as non-dangerous healthcare waste (NDHCW); they were previously considered as household hazardous wastes (HHW). Infectious health care waste (IHCW) comprises: either “waste products presenting an infectious risk, due to their containing viable micro-organisms or their toxins. . .”, or waste products, even in the absence of infectious risk, belonging to one of the following categories: sharp materiel and materials, blood products, human anatomical waste [151,152].

**Waste management is highly dependent on territorial structure and waste management professionals**, entailing sizable costs for healthcare establishments: NDHCW at 100 s– 200 s/ton, and IHCW at 450 to more than 1000 s/ton [152]. The environmental costs of IHCW, which is associated with major logistical constraints (storage, safe transportation, washing and disinfection of containers. . .) are sizable, with GHG emission three times higher than for NDHCW.

Waste disposal control is crucial sustained development, especially insofar as it leads to reduced costs and environmental impact. It is part and parcel of the October 2019 French nationwide waste management plan; of “Pillar 2 “in the April 2021 health-related “Ségur” law and, finally; of the 20 February 2020 law n8 2020-105 pertaining to the fight against wastage and the circular economy. It is equally part and parcel of the eco-conception of health care based on application of the 5 R’s: Reduce, Reutilize, Recycle, Rethink, Research.

Source separation presents the advantages of ensuring personal safety; of complying with hygienic rules and regulations; of mastering the economic incidence of waste elimination; and of optimizing recovery and potential upgrading valorization of the waste generated. The goal of source separation is to steer each type of waste product toward the appropriate sector. The 10 March 2016 French law, known as the “5-flow sorting decree”, imposes source separation of non-dangerous waste products into five basic sectors: plastics, paper/boxes, glass, wood and metals. Even though source separation (except for infectious and specific risks) is seldom carried out in healthcare units, their logistic services have developed sorting sectors, to which some of our NDHCW measures are likely to apply.

Concretely speaking, even if the best waste is that which has not been produced, what am I to do with the HCW waste I have produced? [152–154]

1. To eliminate infectious and related risk: the IHCW sector; OR a specific risk (radiological, cytotoxic or cytostatic drug, chemical. . .): specific, dedicated sector.
2. For the remaining NDHCW: adaptation to the territory and the practices of the relevant service providers. In point of fact, management policies vary, and provisions of treatment may be free of charge or inordinately expensive. Are subject to recovery and valorization:

a. Plastics

i. Classified in seven types, they are all potentially recyclable. Nevertheless, according to your service provider, you will sort either rigid plastics only OR rigid AND flexible plastics OR more finely sorted plastics, by category.

ii. Some of the rigid plastics used in medical devices (corks. . .) can be recovered by associations (cf. the French Bouchons de l'espoir. . .) and be recycled and upgraded in value so as to finance adapted sports equipment, lending more human meaning to your sorting.

iii. Personal protective equipment (cap, gown. . .), disposable outfits, sterile drapes or packaging; these articles are often composed of plastic polymer that cannot be recycled with plastics (or paper). According to where you practice, recovery solutions may (or may not) exist.

b. Paper/small-scale packaging: special attention should be paid to confidential documents (recycling solutions exist), to "shredded" papers (which may or may not be recyclable; it depends on the shredding technique), to plasticized papers (whatever is torn, may be considered as paper).

c. Large-scale packaging: specific sector of waste reclamation d. Glass: pharmaceutical glass is pure glass of which the composition is strictly defined to conserve its neutrality; it differs from glassware for household purposes. Even though glass accounts for more than 30% of overall weight in IHCW facilities, where it is often placed "by default", recycling sectors are few and far between. A specific recovery sector (transport in watertight containers, for example) needs to be created to minimize the risk of staff injury.

e. Wood: seldom applicable in healthcare services.

f. Metals:

i. The blades of laryngoscopes and metal waste, whether or not they are sharp/cutting/trenchant (tweezer, copper alloy surgical scalpel blade, aluminum vials. . .), some coffee capsules

ii. Some of the precious metals (silver, gold, iridium, platinum. . .) present in certain medical devices (cardiology/interventional radiology probes. . .) may be classified in a specific sector and be subject to remuneration by the establishment.

g. Bags/vials/flasks containing incompletely administered (non-cytotoxic) and unutilized drugs: NSHCW sector with incineration. In pratique, the non-specific healthcare waste sector (DIMED, in France) only rarely exists in hospitals, and medication residues are to be thrown out in an incineration sector, according to your territory and to your service providers, usually via the NDHCW (ex-HHW) or the IHCW sector. You must never discard medication residues in wastewater.

h. Bio-waste: In patient rooms or common rooms, certain coffee capsules; as of 1 January 2023, this will be a legal obligation.



i. Batteries: video-laryngoscopes, laryngoscopes, probe housing in cardiology/interventional radiology, other medical devices.

j. Pacemakers.

k. Printer cartridges.

3. Other NDHCW is to be thrown into the black “NDHCW” trash can.

4. Liquid effluents from the operating theatre can be sucked out and filtered before being discharged into waste water. Only the filtering devices are to be eliminated in NDHCW or IHCW, according to whether or not they are infectious.

The objective of sectorization is to facilitate recycling, i.e. the conversion of a waste product into a reusable substance. The interest of recycling consists in reducing waste of raw materials; in reinforcing independent raw material suppl., in reducing energy-related and budgetary expenditures and; in reducing the overall volume of wastage to be eliminated.

Energy recovery by waste incineration is not to be considered as a form of recycling, even if it remains of interest for plastics: an average of 22–44 MJ/kg (except PVC 17 MJ/kg) vs. 18–20 MJ/kg for boxes.

## **ACTIONS**

1. To identify one’s waste products, and to ask the “5R” question: Can I reduce, reutilize or recycle? If not, can I rethink my practices and purchases, and carry out relevant research?

2. To work in collaboration with a waste management unit and the hospital hygiene team

3. To incorporate selective sorting in waste management procedures

4. To optimize existing sorting, and create new sectors

5. To optimize sorting ergonomics; choice and positioning of the containers

6. To inform and sensitize staff to source separation

7. To assess the financial benefits of source separation and recovery of sorted waste in view of financing future sustainable development projects (virtuous circle)

8. To integrate waste sorting in evaluation of professional practices (EPP).

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