HSE

Re-use of Personal Protective Equipment (PPE) during the SARS-CoV-2 (COVID-19) Pandemic: Evidence Summary to August 2020

Prepared by **The Health and Safety Executive**

ER004 (2022)

Evidence Report

Prepared 2020
First published 2022

Scientific evidence about COVID-19 is vital to inform decision making by HSE and across Government. The national and global scientific evidence base about COVID-19 (SARS-CoV-2) continues to develop. Evidence summaries give the best available evidence on specific questions at the time of their preparation in order to inform the COVID-19 response. Subsequent HSE guidance and advice may therefore have been updated.

This rapid evidence summary considers the reuse of personal protective equipment (PPE) for items designed to be used more than once, and for disposable single use items. Re-use of disposable PPE should only be considered as a last resort during pandemic-related equipment shortages and goes against PPE supply and use legislation. In the event that this last resort is unavoidable, HSE has powers under the COSHH Regulations to approve re-use of single use Respiratory Protective Equipment (RPE). This approval requires robust evidence that effective protection is provided by the specific PPE model following defined decontamination protocols.

HSE scientists prepared this evidence summary to inform decision making by policymakers in UK Government and HSE as well as other experts. NHS England and NHS Improvement (NHSE&I) needed to establish whether PPE can be safely re-used after disinfection to support supplies to health care workers during the pandemic. The review considers evidence available from January 2020 to August 2020. The main question considered is: What is the evidence to support the safe re-use of different types of PPE, including face coverings which are not defined as PPE, using different cleaning methods and disinfection technologies?

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

HSE guidance and information on COVID-19 workplace control measures and guidance for safe working in the healthcare settings during the pandemic is at:

https://www.hse.gov.uk/coronavirus/index.htm

https://www.hse.gov.uk/coronavirus/ppe-face-masks/health-social-care/index.htm

(accessed 13 January 2022.)

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Acknowledgements

The authors would like to thank the following organisations who agreed for the results of unpublished studies to be included in this evidence summary. The organisations contributing information included; Inivos Ltd, The British Occupational Hygiene Society, The Royal Academy of Engineers, Bioquell UK Ltd, NHS Scotland and NHS Wales, NHS England, University Hospital Southampton, Wessex Academic Health Science Network.

Key Messages

This summary considered evidence published between January 2020 and August 2020 and was prepared to address a request from UK Government for information about the re-use of personal protective equipment (PPE), and whether after disinfection its performance as PPE will be compromised.

- PPE designed for re-use can be disinfected using a range of methods including thermal treatment, chemical treatment and ultra-violet (UV) irradiation.
- The most suitable disinfection approach will depend on the particular PPE item. Effective disinfection requires good protocols to be developed and followed. Damaged or heavily soiled PPE items should be discarded.
- Re-use of PPE that is designed for single use should only be considered as a last resort. There is evidence that some items can be disinfected without comprimising their performance as PPE. However, some methods can damage material integrity and reduce the effectiveness of the items. This is a particular risk for respiratory protective equipment (RPE).
- If PPE needs to be re-used, behavioural aspects around its use need to be considered. There is evidence that employees can be uncomfortable about wearing RPE previously been worn by someone else, even when the PPE is designed for re-use and can be decontaminated without compromising its performance.
- Reusable PPE manufacturers' instructions for use (including cleaning and disinfection procedures) should be followed. When considering the re-use of PPE users need to assess the likely reduction in its effectiveness if they use alternative cleaning/disinfection procedures not recommended by the manufacturer.
- Medical masks are shown to be better than cloth face coverings to protect the wearer from infection, but there is little evidence yet on the most suitable methods of washing cloth face coverings or whether these degrade over time.
- Any system for re-use of PPE would require strict procedures and instructions for users, and needs to recognise that the results from successful trials of PPE reuse can only be applied to the specific makes/models of PPE investigated and cannot be generalised and applied to all PPE of that type.

Executive Summary

Background

This summary considered evidence published between January 2020 and August 2020 and was prepared to address a request from UK Government for information about the re-use of personal protective equipment (PPE), and whether after disinfection its performance as PPE will be compromised.

Disposable PPE is designed for limited use, with constituent materials not necessarily manufactured to endure extended or repeated wear. Other PPE is designed for re-use under specified usage conditions, either in its entirety or in part. Any PPE designed for re-use still has to be made hygienically safe before re-use and needs to have retained its original protective properties.

The re-use of single use PPE goes against the requirements of GB health and safety legislation. However, for respiratory protective equipment (RPE) only, HSE do have powers under COSHH to 'type' approve RPE, or to approve a standard to conform to. To address the requirement for PPE during the COVID-19 pandemic, substantial work is being carried out in the UK and worldwide on the most effective methods to facilitate the safe re-use of PPE.

Where re-usable PPE or disposable PPE are being re-used, hygienic treatment will involve some form of disinfection or sterilization to render items microbiologically safe. However, because disposable items are not necessarily designed to tolerate chemical (i.e., disinfectant) or physical reprocessing (for example., irradiation, heat), it is imperative that material integrity is subsequently assessed to ensure that wearer protection continues to be adequate. It is the responsibility of the employer to ensure that PPE remains adequate and suitable for use at all times.

An evidence summary was prepared about methods used to disinfect and re-use personal protective equipment (PPE). This summary was prepared to assist HSE policymakers and other government scientists tasked with providing advice to Government. It should be noted that most studies of PPE resuse to date were carried out using surrogate microorganisms rather than the SARS-CoV-2 virus.

Aim

The aim of this rapid evidence summary is to present evidence on the subject of PPE re-use. Some of this is unpublished/pre-publication (pre-reviewed) evidence was not in the public domain at the time of the evidence summary was first undertaken (Sept 2020). Unpublished articles would not normally be included in a review of evidence. In current circumstances with few published studies in relation to PPE reuse and COVID-19, some relevant preprint studies were included but should be regarded with caution until published. Studies published before the COVID-19 pandemic were also considered if they contained relevant evidence regarding the reuse of PPE.

Methods

Specific search term combinations used for publication retrieval were linked to a specific research question. As well as published literature, information was also sought from other authoritative sources such as UK and international Government advice pages and industry and scientific contacts working in the field of decontamination technologies. Supplementary literature searches were undertaken using Google, Google Scholar and PubMed and international scientific contacts were approached to identify relevant unpublished studies.

Evidence based conclusions

A) Behavioural aspects of PPE re-use

- For those re-using PPE, acceptance and confidence are important. This includes confidence in the PPE reprocessing methods, and that rigorous testing and validation of PPE disinfection protocols has taken place. PPE users typically prefer to use personalised equipment, not equipment that has been worn by another user(s) and then disinfected.
- Visibly soiled items of PPE must be discarded to ensure that those wearing reused PPE can be confident in the process.

B) PPE designed for re-use

- RPE designed for re-use can often be disinfected and/or sterilized. However, some treatments require additional steps to ensure complete penetration of more complex items.
- The heat tolerance of re-usable RPE may differ and, if high sterilizing temperatures are used, some components such as plastic polymers may be irreversibly damaged. Low-temperature sterilization methods may also damage respirator components and it is critical to validate these treatments.
- To re-use RPE without compromising it performance, protocols for cleaning and disinfection after use must be developed and followed, preferably with involvement of the supplier. The design of some PPE has influenced the potential effectiveness of decontamination methods.
- Germicidal UV can give measurable pathogen reductions on re-usable plastic goggles, but is generally less effective than chemical fumigation treatments. Germicidal UV does, however, offer the advantage of leaving no chemical residues and is rapid compared to fumigation.
- There are existing, validated methods for re-usable gown decontamination. Gown manufacturers specify the number of disinfection cycles a garment can tolerate, though tracking this to ensure it is not exceeded may be challenging.
- International advice recognising the potential benefits of extended PPE use assumes any clinical use is confined to patients infected with the same pathogen, minimising the risk of disease transmission between patients.

C) PPE designed to be disposable

- Studies confirm that chemical, germicidal UV and heat based treatments can all be effective in reducing microbiological load on RPE component materials.
- Some studies describe impact on PPE material integrity, for example, effects on the protective fit of the RPE to the point where it fails a fit test after re-processing. These physical effects must be monitored to ensure wearer safety.
- For steam sterilization, RPE treatment may be limited to a small number of respirator models and for only one round of autoclaving at 121^{o}C before respirator degradation occurs. Again, these potential failures must be assessed using appropriate testing regimes on representative RPE items.
- Off-gassing of fumigant from porous PPE items may occur, particularly for RPE. Adequate time must be allowed for aeration of treated items prior to re-issue, to avoid worker exposure to harmful chemicals.
- Thermal or chemical treatments of protective gowns or coveralls must consider whether their protective qualities are maintained after processing.
- As with other PPE, the re-use of visibly heavily soiled or damaged items should be avoided.

D) Face coverings

- A cluster randomised study showed that rates of respiratory illness transmission were higher in a cloth mask cohort, compared to using medical masks. Penetration testing showed that passage of particles through cloth masks was high (97%) compared with medical masks (44%). An assessment of N95 type respirators showed less than <0.01% penetration.
- The European Centre for Disease Prevention and Control (ECDC) advises against use of cloth masks in the clinical setting, stating that penetration of viral particles is significantly higher than when wearing surgical masks.

Contents

1. Introduction

The national and global scientific evidence base for COVID-19 (Sars-CoV-2) continues to develop. Rapid evidence summaries have been commissioned to address specific questions to inform the COVID-19 response; they are based on evidence avialable at the time of their preparation. Subsequent HSE guidance and advice may therefore have been updated since the original review publication data.

1.1 The review question

This evidence summary addressed a request for information about the re-use of personal protective equipment (PPE) and how re-use could be achieved. Activities related to PPE re-use, or extended use, span occupational sectors and the public, but primarily affect workers such as healthcare professionals and public facing service providers. The original information request included face coverings, which are not defined as PPE but are now widely used by many members of the public and in certain occupational settings. These are also considered here. At the request of NHS England and NHS Improvement (NHSE&I) – the information has been considered within two main categories:

- PPE designed for re-use and,
- PPE designed for single use only (disposable)

Face coverings are considered within a separate section and information related to behaviours and the re-use of PPE is considered.

1.2 Context

Since March 2020 the subject of PPE has rarely been out of the UK news and has received unprecedented media coverage at national and international level. The rapid escalation, impact and scale of Sars-CoV-2 infections and the consequent need for healthcare support for many of those affected, has imposed equipment supply pressures on healthcare services that were never fully anticipated.

Staff within the National Health Service (NHS) and wider social care services in the UK must have access to PPE ensembles that are safe, effective and available in quantity, to match the workloads placed on them. The intensive demands of Sars-CoV-2 patient care, along with continued uncertainties about viral transmission and infectivity, have led to the large-scale discarding of items such as face visors and protective garments that might otherwise have been cleaned, disinfected and re-used. As well as the obvious needs of the healthcare sector, the staged return of many other sectors to some form of working normality means that items such as visors, respiratory protective equipment (RPE), disposable gloves and aprons are now being widely used by many workers outside of the healthcare setting and by members of the public, placing additional supply demands on these items. The ongoing need to protect staff puts additional financial pressures on companies and public services because in most cases, PPE is constantly discarded and must be replaced with new. While the initial acute crises around healthcare worker PPE

supply are in some abeyance, future PPE provision is now being considered ahead of a possible winter second wave of infections in the UK.

Options for reuse of PPE:

In order to reduce pressure on NHS PPE supply chains, but also to ensure a supply of PPE to other sectors and the public too, some recent studies have considered the cleaning, disinfection and/or sterilization and re-use of some items of PPE, specifically in relation to Sars-CoV-2. However, the whole subject of PPE re-use is fraught with both technical and emotive questions. The disinfection and sterilization treatments that can render PPE and component materials microbiologically safe for re-use may affect the integrity of the treated items. This has implications for PPE and RPE protection factors, equipment fit and, therefore, the safety of the PPE wearers. Important too for any user is the concept of wearing a PPE item that has been used previously, maybe even by someone else. It is for these reasons that the UK Government previously provided information for PPE re-use and sessional use based on advice and research conducted by PHE, HSE and others (PHE/Gov.uk, 2020; information withdrawn 16.09.20). This advice was in place between April and September 2020, covering a period when the UK Government faced severe PPE shortages. The Gov.uk website currently states that the withdrawn advice will be re-issued as and when required and in line with current scientific advice. In its earlier form Government advice described the specific circumstances when re-using PPE should be considered. These were:

- "The sessional use and re-use of PPE when there are severe shortages of supply".
- "where items of PPE are unavailable" and that such actions "should be considered as temporary measures until the global supply chain is adequate to meet the UK's needs."

PPE resilience plans

A new PPE resilience plan has been published by the Government (Gov.uk, Sept 2020a) following the withdrawal of the earlier document. This provides detailed information about future strategies to assess the viability of PPE re-use, in particular RPE, stating:

> "**Safe repurposing of single use PPE in emergency circumstances**: We want to ensure that in the event of an emergency response, we have options for safe, effective decontamination of single use PPE where other options for securing supplies have been exhausted. Our current focus is on FFP3 respirators. This is the most challenging item in terms of global availability and costs have escalated considerably compared with historical pricing. To ensure resilience and provide emergency provision of respirators in this challenging circumstance, countries are exploring whether it is possible to decontaminate single-use FFP3s so they can be re-used."

Related to this, the UK Government acknowledges end user concerns about PPE re-use, stating,

> “We will work with the Royal Colleges and Unions to understand the assurances and information that staff will need to feel comfortable and confident in safely reusing PPE.”

Major organisations like the US Centers for Disease Control and Prevention (CDC) also make a clear statement about PPE re-use and extended use. CDC provides detailed information on this practice, but also raises important infection prevention and control (IPC) considerations relating to the re-use of some equipment:

> “High-level and continued efforts will be needed to maintain and scale-up the PPE supply chain to ensure availability of PPE in healthcare settings where it is needed, to avoid supply shortages, and allow adherence to IPC standard practice. Wherever possible, emergency PPE strategies should not be used in hospital wards housing severe or critically ill patients with COVID-19, as well as those with known co-infections of multi-drug resistant or other organisms transmitted by contact (for example ,Klebsiella pneumoniae) or droplet (for example, influenza virus).” – (CDC, 2020a).

It is within this context that the information below should be viewed.

1.3 Methodological uncertainties for testing re-used PPE

UK Technical Groups

As the pandemic crisis unfolded in the UK, various technical groups were established to consider PPE, its quality (for example overseas imports), correct use and its potential re-use. The Cross-Government PPE Decontamination and Re-use Group, consisting of regulators, healthcare decontamination specialists and devolved authority representatives, undertook a rapid review on disposable PPE decontamination methods and PPE types. This group settled on considering one of the most difficult to source items, FFP3 respirators (evidence communicated to HSE). Steam sterilization at 121˚C for 15 minutes was deemed to be technically feasible as an approach for a very limited number of models of respirators, as many were adversely affected during the process. Further work also continues on two different types of hydrogen peroxide vapour decontamination methods, as outlined in the UK Government PPE resilience plan. (Gov.uk, Sept 2020a).

Rowan and Laffey Review

Rowan and Laffey, (2020) reviewed some of the inherent challenges in re-using PPE. The authors reported that the lack of published data on PPE re-use is because most of these items are manufactured as single use items. This in turn generates a reliance on information generated by medical device manufacturers and related sterilization industries, to help understand how best to address this shortage of PPE and the need for reprocessing in a pandemic. The opinion of Rowan and Laffey (2020) is that limited knowledge sharing occurs in the medical technology sector so as to protect intellectual property rights. However, the authors believe there is an increasing trend by leading industries to publish findings that also assist in shaping

PPE test standards, guidelines and regulations. Equipment manufacturers of one-use-only PPE have, according to the authors, recently provided new information on possible methods for reprocessing these items given the universal need to provide a contingency plan arising from shortages during the Sars-CoV-2 pandemic.

Royal Academy of Engineering review

Because so much PPE is designed for single use, reprocessing can introduce questions about the quality and effectiveness of the PPE following the decontamination process. The Royal Academy of Engineering (RAE, 2020) recently undertook a review to consider international PPE reprocessing practices and refer to a factsheet issued by the Institute of Healthcare Engineering and Estate Management (IHEEM). The factsheet highlights six ways in which PPE function may be compromised by reprocessing. Specifically, it states that before deploying a reprocessing method there must be confidence that the risk that the efficacy of the PPE may be compromised in any of these ways is as low as is reasonably practicable. The six considerations are:

Material compatibility - the compatibility of the materials exposed to the decontamination method will depend on the approach taken, type of PPE, brand and even the specific design. For more complex items, such as respirator masks, how its constituent parts respond should also be considered.

Physical damage - removal of PPE may result in physical damage, creating holes in the fabric or damage to the materials employed to ensure a good fit. Careful inspection before re-use would need to be carried out to ensure no such physical damage had occurred.

Residuals - the consequences of cleaning and sterilant residuals must be considered for the safety of wearers. Different decontamination approaches and the degree of skin contact will affect this. The process should also be checked for the presence of malodours following treatment.

Viral inactivation - after use, PPE may contain coronavirus contamination embedded within a matrix of spittle and sputum. Salts from perspiration of the wearer may also be present. Decontamination must be validated for coronavirus inactivation and other residual microbes.

Material performance - certain reprocessing conditions can damage the critical material properties, such as the extent to which gowns are splash-proof or the structure and electrostatic attraction properties of the respirator mask's filtration system, making it less effective.

Respirator fit - reprocessing and repeated use of single-use PPE can damage the shape, fit and elasticated attachment of respirators. The capability to retain fit seals must remain effective after reprocessing.

The RAE (2020) also states that before use, any decontamination method should be evaluated against these risks for its ability to retain PPE functional performance, fit characteristics achieved prior to decontamination and safety of the wearer. The PPE should meet the original ISO standard following any reprocessing procedure.

The British Occupational Hygiene Society

The British Occupational Hygiene Society (BOHS) set up an expert panel to assess the potential for RPE re-use, and the panel undertook a review of the published evidence. Information gathering spanned a number of years (not just the COVID-19 outbreak period), but the review was not published because the group had fundamental concerns about the context underpinning much of the retrieved research. For example, the BOHS panel stated that while the study recognised the technical feasibility of decontamination, they concluded that the baseline of the research quality was "*..low,* for example*, showing no real understanding of basic virology or even the difference between a virus and a bacterium*", or an "*absence of proper validation, poor data sets*" (evidence communicatd to HSE). The BOHS went on to list particular areas of concern, including:

- The testing methods used in all their retrieved studies did not deal with contamination that had arisen in a real-life context.
- The retrieved research, even if it was not using a non-comparable remote proxy contaminant, used a proxy contaminant, but not bound into aggregation with other substances. This was a fundamental issue for BOHS in respect of the validity of the research.
- Sample sizes were felt to be too small to create a statistically viable basis for determining in-use failure rates. The BOHS panel stated that recent studies and evidence from the US confirms that there is a predicted failure rate.
- A concern not addressed in the retrieved research was that the studies tended to address decontamination from COVID-19, but not from other potential infections which BOHS stresses "*.can be lethal*". Also, the focus was on 'decontamination', not sterilization.

Despite these conclusions, those preparing this literature review recognised that the highest quality studies, such as meta-analyses and randomised control studies, associated with clinical research are uncommon in occupational settings. These limitations apply to studies of PPE re-use despite the number of publications on this topic.

2. Methods

2.1 Literature search

In view of the limitation in the published evidence, in this evidence summary trends from multiple independent studies were sought even if derived from smaller studies. Not all such studies have utilised ‘live’ Sars-CoV-2, for example, in challenge tests for PPE, and many research teams may not be equipped to undertake such tests. However, recently published data using surrogates provide useful read-across for Sars-CoV-2 PPE topics. With this in mind, the following criteria were applied to the retrieved evidence:

- The research provided relevant evidence to answer the research question (i.e. information related to PPE re-use)
- The paper was preferably written in English (deadlines for rapid reviews rarely permits translation)
- Where possible the paper was peer reviewed for publication in an established scientific journal, or else was presented in well written pre-publication form by a journal, pending peer review
- Any ‘grey literature’ was obtained from an authoritative and citable source
- The methodology used in the papers was clearly described and traceable
- For technical publications and in addition to their conclusions, the authors identified any uncertainties introduced by their methodology, or constraints on the research.

The specific search terms used by HSE’s Information Centre, and the accessed databases, are described in Appendix 3 of this document. Additional information was received from other authoritative sources and industry contacts working in relevant sectors. Supplementary literature searches were undertaken using Google, Google Scholar and PubMed where required.

2.2 Objectives

With reference to the original enquiry question (above), this knowledge summary seeks to present evidence on the subject of PPE re-use, some of it currently unpublished or so far released only in pre-publication (pre-reviewed) format. This included some examples of unpublished evidence gathered by HSE scientists collected to support the expert bodies advising the UK Government on the COVID-19 pandemic. Previously published (pre-COVID19) reports were also considered if relevant and offered 'read across' for the current Sars-CoV-2 pandemic and related PPE re-use.

3. Re-useable personal protective equipment

3.1 Overview

Some PPE is designed for re-use under specified usage conditions, either in its entirety or in part. For example, the pump housing, air feed tubing and hood of a powered air purifying respirator (PAPR) are designed to be re-used, with appropriate cleaning and/or disinfection between uses for hygiene purposes. For some items the line is less clear; for example, some impervious aprons worn in areas like mortuaries are designed for re-use, with cleaning and disinfection between cases. However, the use of disposable plastic aprons is now widespread within healthcare and doffing of disposable aprons is regarded as safer than having to remove and disinfect re-usable items. Other PPE items normally regarded as re-usable for example, face shields/visors, have largely been treated as disposable during the current Sars-CoV-2 outbreak. Not because they cannot be cleaned and disinfected, but because re-use has been difficult for example, due to the rate of use in front line care. There also are concerns about surface contamination and viral transmission risks for staff; and lack of time and resource to reprocess this type of PPE papidly without compromising their performance. This has meant that millions of potentially re-usable PPE items have been disposed of after a single use over recent months.

3.2 Summary of evidence for this section

- Studies show that RPE designed for re-use can often be disinfected and, in some cases, sterilized by autoclaving or other means. However, treatments such as chemical fumigation may require additional steps to ensure complete penetration of more complex items, for example, air-feed tubing used for powered RPE.
- The heat tolerance of re-usable RPE varies and if high sterilizing temperatures are used this may irreversibly damage some component materials such as plastic polymers. The delicacy of such components may therefore make heat-based sterilization impossible. Low-temperature sterilization methods (for example, ethylene oxide, gamma irradiation) may also damage respirator components and validation of treatment methods is therefore critical, even for RPE designed for re-use.
- To re-use RPE particularly within the frontline healthcare setting, protocols for cleaning and disinfection after use must be developed and followed, preferably with supplier advice. Errors in reprocessing have been reported. Sterilization of RPE prior to re-use provides the maximum level of confidence, but may not be possible for reasons stated and in a central processing department can pose many practical challenges and careful logistical planning.
- The design of some PPE has influenced pathogen reduction. For example, bacterial challenges used in hydrogen peroxide fumigation tests for face visors could not all be killed when placed around the thick foam head band. Other work with similar fumigant was more successful, reporting high levels of microbiological kill even in awkward equipment locations and with no damage to visor clarity. These variables mean that levels of efficacy require validation for a particular item

and process. Eye protection re-use is an example of a process subject to existing infection prevention and control instructions, which may not always be compatible with re-use procedures.

- Germicidal UV has demonstrated measurable pathogen reductions on re-usable plastic goggles, but is generally less effective than chemical fumigation treatments. Even within the confines of a compact UV cabinet the observed log reduction of a bacterial challenge was variable. Germicidal UV does, however, offer the advantage of no chemical residues and is rapid (typically 15-45 minutes), compared to fumigation (hours).
- Re-usable gowns are widely used in healthcare and there are existing validated methods for their decontamination, for example, the infectious linen cycle detailed in Department of Health guidance HTM01-04. Gown manufacturers specify the number of disinfection cycles a garment can tolerate, though tracking this to ensure it is not exceeded may be challenging.
- International advice recognises the potential benefits of extended PPE use, for example, not removing eye protection between patients, unless visibly soiled or condensation is present. However, this assumes clinical use is confined to patients infected with the same pathogen, minimising the risk of disease transmission between patients. A recurring message is to discard any heavily soiled or visibly damaged items and to avoid re-using them.

3.3 Supporting evidence: re-usable Respiratory Protective Equipment (RPE)

Powered air purifying respirators (PAPR)

PAPR systems comprise a motor to deliver filtered, purified air under positive pressure to the wearer, usually into a loose-fitting hood or helmet with integrated visor. They offer the advantage over tight fitting (filtering facepiece; FFP) respirators in that they do not require fit testing, can be worn by persons with facial hair, and can be less burdensome for longer-term wear. In industry, they are widely used in areas where the high level protection of a full PPE ensemble is required, such as in asbestos removal. In healthcare, they are routinely used in high consequence infectious diseases units as protection against highly infectious airborne transmissible pathogens for example, monkeypox (Kratz, et al. 2019).

Some or all of the components (head and face covering, air mover motor, connecting air hose and filter housing) are re-usable. In some PAPR systems the reusable components (air mover worn on a belt at the waist with an air hose connecting to the hood) must be worn outside the protective gown or coverall component of the PPE ensemble therefore there is the potential for these components to become contaminated and require decontamination. In others, the air mover and filter are integral to a headset unit worn under a protective hood and integrated visor. A belt-attached power pack drives the unit, connected by a cable to the headset, and these components can be worn under PPE (evidence collected by HSE scientists to support the NHS COVID-19 response).

Despite somewhat less favourable ratings on comfort and communication, experienced half-mask respirator and PAPR users still prefer reusable respirators over disposable respirators in certain higher risk scenarios. This suggests that reusable respirators are an acceptable alternative to disposable respirators in health care and offer a viable solution to prevent pandemic-generated respirator shortages (Hines, et al. 2019). This benefit does need to be balanced against the increased cross-infection risks associated with doffing and manual cleaning and disinfection methods.

The study of Cramer, et al. (2020a) assessed the treatment of an assortment of PPE using an ionized hydrogen peroxide system (iHP, generated by SteraMist® equipment). Re-usable RPE in the test included the Sentinel® XL CBRN hood model with hose, Sentinel® head cover hoods, Sentinel® PAPR breathing tubes for use with Sentinel® XL HP PAPR (ILC Dover, Frederica, DE), and Bullard RT Series PAPR hood (Bullard, Lexington, KY). For the PAPR components and other equipment, *Geobacillus* biological indicators were placed on surfaces that were judged to be least accessible to the sterilant, for example, inside the PAPR tubing. Biological indicators (BIs) placed within PAPR hoods achieved 9-$\log_{10}$ kill as did a BIs placed in a PAPR hose that was pre-treated using a SteraMist handheld spraying device. However, two BIs placed inside either end of a PAPR hose not subjected to pre-treatment, were not sterilized. Cramer, et al. (2020a) concluded that penetration of fumigant into semi-enclosed spaces such as PAPR hoses was less efficient than for more open equipment, such as N95 masks, but PAPR hoses could still be sterilized by pre-treatment with a handheld iHP-delivery device followed by a cycle of iHP treatment in a chamber.

Hao, et al. (2020) evaluated the effect of VHP (vapourised hydrogen peroxide) on the disinfection of PAPRs within a fumigation sterilization cabinet. They concluded that a 60 minute disinfection cycle with an airflow of 11.4 ±0.9 m^3/hr and a hydrogen peroxide consumption of 50 ±30g was effective against *Geobacillus* biological indicators and that the function and material physical properties were unaffected by the disinfection.

Half face mask respiratory protective equipment (RPE)

It can be argued that this is where future RPE work needs to focus, to achieve sustainability and security of supply. Reusable RPE includes respirator made from elastomeric materials (flexible polymer materials resembling rubber) that can be cleaned, disinfected, and re-used (Clever, et al. 2019). By design, these items are intended to be worn multiple times, cleaned and re-used and therefore need to be supplied with cleaning and disinfection instructions (according to the PPE Regulation). However, unless the product is specifically marketed towards healthcare, then the cleaning and disinfection instructions may be generic and not particularly suited for infectious agents in healthcare. In a further comment about elastomeric design half masks Clever, et al. (2019) also – somewhat prophetically - conclude that reusable elastomeric respirators could be a viable option for use as needed in surge situations (for example, influenza pandemic, airborne transmissible disease outbreak, unknown hazard). However, the US authors also acknowledge that this would be subject to addressing logistic and implementation challenges,

> "..including challenges related to cleaning, disinfection, and storage, as well as just-in-time fit testing and training for staff unfamiliar or untested for these respirators. A smooth transition to surge use would be expedited and enhanced if reusable elastomeric respirators were a part of the health care facilities' day-to-day respiratory protection program."

Bessesen, et al. (2015) concluded that when following the manufacturer's instructions for cleaning and disinfection of half-mask respirators, untrained and unsupervised healthcare workers made multiple errors. To re-use respirators, protocols for cleaning and disinfection after use must be developed and followed to ensure their function will not be compromised. The procedures should be broadly applicable to the challenging conditions that may exist in a pandemic of infection spread by the respiratory route. Sterilization of respirators prior to re-use would provide the maximum level of safety, but sterilization in a central processing department poses many practical problems. Limitations imposed by temperatures which can be used on respirators and the delicacy of some of the components make steam sterilization impossible. Low-temperature sterilization methods (for example, ethylene oxide, radiation) also may damage respirator components. Intermediate-level disinfection of respirators would be adequate to destroy influenza and most respiratory viral pathogens.

Recently a respirator manufacturer undertook efficiency and fit testing on their half-mask respirator model and changed the instructions for use to allow 8 cycles of steam sterilization at 121°C for 15 minutes. This would enable hospitals to use their existing decontamination process streams to disinfect this model of re-suable respirator in accordance with existing validated decontamination methods for healthcare (i.e. Department of Health HTM01-01 Part C guidance). Authorising Engineers in NHS Scotland are currently exploring different respirator models (excluding P3 filters) to see whether they withstand washer-disinfector cycles in accordance with Department of Health HTM01-01 Part D guidance (evidence communicated to HSE). Commercial equipment suppliers are also starting to provide disinfection services and equipment that may help to support this RPE re-use approach and are claiming up to a 5-log reductions in contaminating pathogens (IOSH, 2020).

A key challenge, as perceived by HSE and the NHS is the need for engagement with manufacturers. For manufacturers to revise their 'instructions for use' (IFU) to enable healthcare-acceptable disinfection or sterilization processes, they would need to see a suitable return on their investment. To this end, Central Government almost certainly have a role in encouraging and supporting manufacturers (for example, with an underpinning promise of orders, when such IFU make these RPE suitable for healthcare use in outbreak situations) (evidence communicated to HSE).

3.4 Supporting evidence: eye protection

Visors/face shields

The study of Cramer, et al. (2020a) assessed the treatment of various PPE using in ionized hydrogen peroxide system (iHP, generated by SteraMist® equipment). This included a limited assessment of two models of face shields, one locally fabricated

and the other a Fisherbrand™ Disposable Face Shield (Fisher Scientific). These and other PPE items were spaced 6 cm to 20 cm apart on stainless steel shelves within a purpose designed exposure chamber. One face shield was pre-treated with a SteraMist handheld spraying device prior to processing in the chamber. This comprised spraying the equipment from a distance of approximately 0.5-1.0 m for a few seconds per surface. BIs embedded in the thick foam at the top of a Fisherbrand Disposable Face Shield were not sterilized.

Even with pre-treatment, sterility was not achieved with this thick face shield foam, with the authors concluding that normally disposable PPE of this type should not be re-used. When the authors tested the effect of pre-treating the same face shield with a hand-held SteraMist device (after inserting a new BI) they observed a 4-$\log_{10}$ spore kill, which failed the 6-$\log_{10}$ threshold conventionally used to score successful sterilization. In contrast, an FDA approved custom-fabricated face shield, consisting of 3D printed parts, appeared to be sterilized effectively based on the same bacterial spore treatment verification.

Public Health Ontario (PHO, 2020) summarise information from a review of the literature undertaken in spring 2020. They describe how eye protection is available in various forms, such as face shields and visors attached to surgical masks and that both disposable and reusable options are available. The PHO authors cite a study of protective spectacles that used a germicidal UV light cabinet treatment (at 253.7 nm wavelength) and the bacterium *Staphylococcus aureus* as the indicator organism (Ziegenfuss, et al. 2018). Using minimal UV doses, that study demonstrated a 2.4 log10 reduction in S. aureus post-UV treatment. The Ziegenfuss (2018) study was based around lateral transmission for example, between wearers of the same device with decontamination between uses, such as visitors at an industrial site. PHO (2020) also refer to the CDC's strategies for optimizing eye protection supply (CDC, 2020b). These include:

- Shifting from disposable to reusable eye protection (for example, goggles, safety glasses with tight adherence to the face and arms without vented areas, powered air purifying respirators).
- Considering extended use (not removing eye protection between patients, unless visibly soiled or condensation is present), assuming clinical use is confined to patients infected with the same pathogen.

Saini, et al. (2020) reported the use of vaporised hydrogen peroxide (VHP) for the treatment of an assortment of PPE, including face-shields previously obtained for BSL-3 laboratory work and from hospital supplies of PPE for healthcare workers.

The study used a range of concentration of VHP, 6, 8 and 10% prepared with distilled water from a stock concentration of 11–12% stabilized with silver nitrate (0.01%). To ensure effective disinfection three bacterial indicators were used; *Escherichia coli*, *Mycobacterium smegmatis* and spores of *Geobacillus stearothermophilus*. No viral challenges were included but the authors emphasise that *G. stearothermophilus* is regarded as the 'gold standard' for sterilization testing. Test items were 'spiked' by inoculation with ~ 10^7 CFU/ml of *E. coli* and *M. smegmatis*, individually. 100 µl of each bacterial cell suspension were spread uniformly and air dried. *G. stearothermophilus* spore strips were placed at far corners

of the treated room, in difficult to access areas. The efficacy and impact of repeated VHP treatments was assessed, including examinations of material integrity.

Following treatment complete elimination of *E. coli* and > 7 log_{10} reduction in *M. smegmatis* were observed and *G. stearothermophilus* spore preparations also failed to grow. No visual blurring/opacity was noted for the face-shields to indicate any material deformity and the authors concluded that the process was fully compatible with the face-shield materials. However, emphasis was placed on the need to discard any heavily soiled or visibly damaged items and to avoid re-using these.

Goggles/safety glasses

Ziegenfuss, et al. (2018) investigated the use of germicidal UV light decontamination within a purpose designed UV cabinet and assessed its efficacy in routine decontamination of reusable plastic safety glasses. The microbiological challenge was limited to one bacterial type, *Staphylococcus aureus*, rather than using virus. Six items of inoculated safety glasses were placed in the UV cabinet to facilitate UV based surface disinfection. Glasses were new at first use and decontaminated with 70% ethanol prior to inoculation and were positioned equidistance but utilising all parts of the cabinet. The cabinet was operated for a standard cycle of 15 minutes for all testing and the UV dose was calculated based on the use of a bulb that was half way through its life cycle of 3500 hours; the UVc dose varied from ~3.610^{7}mW/cm^2 for glasses at an upper position in the cabinet to ~1.0810^{8}mW/cm^2 for glasses in a lower position.

A significant 2.4-log_{10} reduction of bacterial contamination (colony forming units) was seen (P< .05), based on median cfu counts. The authors state this was independent of the location of the glasses within the cabinet. There was a significant interaction (P = .013) between location of the glasses in the cabinet and inoculation point on the glasses. The greatest reductions were on the nosepiece of the glasses at a lower corner position in the cabinet (3.43 log_{10}). The least reduction was on the inside earpiece at an upper position in the cabinet (0.28 log_{10}) The authors concluded that the use of a UV cabinet is recommended as an effective and convenient option for reduction of microbial contamination of plastic safety glasses between uses. However, they cautioned against improperly maintained UVc devices, which could lead to eye and skin damage. The scope of this project was limited to bacterial contamination of plastic safety glasses and that additional research would be needed to determine the ability of the cabinet to reduce or eliminate viruses.

Jinia, et al. (2020) reviewed a number of disinfection technologies for PPE re-use during the pandemic, with the main focus placed on FFPR treatments. However, the authors refer to US CDC (2019b) advice that provides guidance for the re-use of various items of eye protection, in response to the Sars-CoV-2 pandemic. CDC (2019b) suggested specific measures, including the following:

- Shift eye protection supplies from disposable to re-usable devices (i.e. goggles and reusable face shields).
- The preferential use of powered air purifying respirators (PAPRs) or full-face elastomeric respirators which have built-in eye protection.

- Ensuring appropriate cleaning and disinfection between users if goggles or reusable face shields are used**.

The CDC (2019b) defines the extended use of eye protection as the practice of wearing the same eye protection for repeated close contact encounters with several different patients, without removing eye protection between patient encounters. Importantly, they state that extended use of eye protection can be applied to disposable and reusable devices. There remain strict recommendations for extended use, as follows:

- Eye protection to be removed and reprocessed if it becomes visibly soiled or difficult to see through.
- If a disposable face shield is reprocessed, it should be dedicated to one healthcare worker and reprocessed whenever it is visibly soiled or removed prior to putting it back on.
- Eye protection should be discarded if damaged in any way
- Healthcare workers should take care not to touch their eye protection. If they touch or adjust their eye protection they must immediately perform hand hygiene.
- Healthcare workers should leave patient care area if they need to remove their eye protection.

In terms of the reprocessing method(s) then CDC (2019b) provide the following advice**:

- Adhere to any recommended manufacturer instructions for cleaning and disinfection. This may, for example, be important in relation to material compatibility issues.
- When such instructions for cleaning and disinfection are unavailable, such as for single use disposable face shields, consider:
- While wearing gloves, carefully wipe the inside, followed by the outside of the face shield or goggles using a clean cloth saturated with neutral detergent solution or cleaner wipe.
- Carefully wipe the outside of the face shield or goggles using a wipe or clean cloth saturated with EPA-registered hospital disinfectant solution.
- Wipe the outside of face shield or goggles with clean water or alcohol to remove residue.
- Fully dry (air dry or use clean absorbent towels) then remove gloves and perform hand hygiene.

3.5 Supporting evidence: protective gowns

PHE/Gov.uk (2020) provides general advice about gowns if supply is critically affected in the healthcare setting during surge situations; the advice relates to both re-usable and disposable gowns. The advice is to preferentially use fluid repellent hospital gowns or coveralls for the care of patients in high risk areas, where aerosol

generating procedures (AGPs) are being performed. In addition, the advice indicates three main options as alternatives if gowns are not available:

- Reserve disposable, fluid repellent gown or coveralls for AGPs and surgical procedures.
- Disposable, non-fluid repellent gowns or coveralls with a disposable plastic apron for high-risk settings and AGPs with forearm washing once gown or coverall is removed.
- Re-usable (washable) surgical gowns or coveralls or similar suitable clothing (for example, long-sleeved laboratory coat, long-sleeved patient gown or industrial coverall) with a disposable plastic apron for AGPs and high-risk settings with forearm washing once gown or coverall is removed. These would need to be washed in a hospital laundry and capacity for hospital laundries may need to be increased.

In the UK, reusable gowns are routinely used in healthcare and there are existing validated methods for effective decontamination, for example, the infectious linen cycle detailed in Department of Health guidance HTM01-04 (2016 a and b). The gown manufacturers specify the number of cycles of disinfection that a garment can go through; however, difficulties can occur with tracking of individual garment through its life cycle to ensure that cycle life is not exceeded.

Public Health Ontario (PHO, 2020) undertook a literature search in Spring 2020 using the search terms “decontamination” and “gown” and retrieved no published studies on decontamination and re-use of gowns. This outcome may reflect the search strategy employed but does underline the dearth of data in this topic area. PHO states that cloth gowns should be laundered after each use and that a combination of mechanical, thermal, and chemical factors results in the antimicrobial action of the laundering process – but that protocols may vary. Despite the ability to reprocess these items, PHO opinion indicates that, “*Reprocessing of disposable gowns is impractical due to the inability to launder, remove contamination and maintain integrity*.” Their current opinion on the re-use of cloth gowns takes its lead from CDC (2019a) published guidance.

3.6 Supporting evidence: re-usable aprons

These are more common in work environments such as abattoirs and during the handling of human remains, but even in these environments the use of disposable aprons is increasingly common (HSE, 2018). The materials used for apron manufacture may not be compatible with heat based treatments and UVc may damage certain plastics following repeat exposures (Hankett, et al. 2013); thus chemical disinfection processes are more likely to apply. Standard HSE advice is to decontaminate any re-used items following the equipment supplier’s recommendations and then to ensure items are stored in a clean, dry condition prior to re-use.

4. Disposable personal protective equipment

4.1 Overview

One-use-only or disposable PPE is designed so constituent materials are not necessarily manufactured to endure extended or repeat use by the wearer(s). Any re-use of such items, whether RPE, gowns, eye protection or other forms of PPE is further complicated by the need to ensure that items are made microbiologically safe for re-use and that the PPE retains its original protective properties following the applied treatment. This treatment normally requires some form of disinfection or sterilization. Because such items are not normally designed to tolerate chemical reprocessing, extreme heat, or other forms of treatment to render them microbiologically safe, ongoing material integrity is of primary concern to provide continued and adequate protection.

4.2 Summary of evidence for this section

- The majority of evidence on disposable PPE relates to RPE. Numerous studies exist, most using bacterial or bacteriophage challenges rather than pathogenic viruses. These surrogates may not be structurally similar to the Sars-CoV-2 virus but are often regarded as more robust and harder to eradicate than the Sars-CoV-2 virus.
- Published and unpublished studies confirm that chemical, germicidal UV and heat based treatments have been assessed for the treatment of FFR type respirators and these treatment methods can reduce microbiological load on RPE composite materials.
- Whilst confirming the hygienic efficacy of treatments, several studies also describe significant impact on PPE material integrity, for example, effects on the protective fit of the RPE to the point where it fails a fit test after re-processing. Elasticated straps and nose bridge foam are at particular risk of degradation from UV and heat based treatments. For chemical and UV treatments the maximum number of disinfection cycles will be limited by the respirator model and the treatment intensity required to eliminate the pathogen. These physical effects on PPE/RPE integrity and performance must be monitored to ensure wearer safety.
- For steam sterilization, RPE treatment may be limited to just a small number of respirator models and for only one round of autoclaving at 121^{o}C before respirator degradation occurs. Material changes and a reduction in filtration penetration are the biggest failure modes following autoclaving. Again, these potential failures must be assessed using appropriate testing regimes on representative RPE items.
- Off-gassing of fumigant from porous components of PPE is an area of concern and uncertainty, particularly affecting RPE. Chemical residues may be irritant or toxic and will be influenced by RPE material composition and overall design. Adequate time must be permitted for aeration of treated items prior to re-issue, to avoid worker exposure to potentially harmful chemicals. This effect is being studied in some detail as part of ongoing Government funded research, with

technical oversight provided by Public Health England (PHE) and the Health and Safety Executive (HSE).

- Thermal or chemical treatments of protective gowns or coveralls must consider whether their protective qualities, for example, splash resistance, are maintained after processing. Recent pilot studies in the UK, led by Government scientists and supported by industry, have shown that it is feasible for single use surgical gowns to be laundered for re-use and still provide spray protection. Even the addition of hydrogen peroxide fumigation did not affect material integrity based on in-house spray testing and the process eradicated a heavy inoculum of bacteria, including spores. However, the study was acknowledged as having low statistical power and only tested one garment type.

4.3 Supporting evidence

Government Guidance on Respiratory protective equipment (RPE)

Disposable Filtering Face Pieces (FFP2 and FFP3)

Re-usable RPE items, described earlier, represent only a small proportion of the RPE worn in health care globally. The vast majority is single use / disposable RPE of the tight-fitting filtering facepiece (FFP) type. These are devices constructed largely from filtering materials worn on the face that prevent inhalation of viral aerosols by the wearer (Brosseau & Sietsema, 2020). In the UK and Europe this comprises equipment complying with EN 149 (2009) and these are either FFP2 offering 94% protection from penetration of particles, or FFP3 offering 99% protection. In the US, FFRs can potentially be worn many times, i.e. they are disposable but not regarded as single use. Also, there is no requirement that only respirators with the N95 designation must be used. Brosseau & Sietsema, (2020) confirm that any filter designation, N, P, R and 95, 99, 100, will provide a similar or higher level of protection. In other European countries (ECDC, 2020c), and based on WHO guidance (WHO, 2020), FFP2 RPE is mainly worn for respiratory protection during COVID-19 patient care. However, in the UK, on a precautionary basis and following the COVID-19 infection prevention and control (IPC) guidelines (UK Government, 2020) FFP3 RPE is recommended for wear during aerosol generating procedures with COVID-19 patients.

The US Centers for Disease Control and Prevention (CDC, 2020c) provides advice related to the use of N95 respirators, a close equivalent to UK FFP2. This advises how disposable RPE might be used when there is justification for its use beyond the intended life of the item. The CDC provides a flow chart and related online tools to assist end users in determining whether an emergency strategy is required for N95 re-use (Appendix 1).

Within its advice CDC defines re-use approaches in two ways: 1) When there is ‘limited’ Filtering Facepiece Respirator (FFR) re-use, defined as *“..the practice of using the same N95 FFR or other filtering facepiece respirator for multiple encounters with patients but removing it (doffing) after each encounter*”. This is characterised by CDC as different from (2) ‘Extended’ use of an FFR, i.e. *“.where the same FFR is worn continuously for encounters with multiple patients*”. During limited

re-use, the FFR is stored in between encounters to be put on again (donned) prior to the next encounter with a patient.

The CDC describes how decontamination of N95 FFRs may be considered as part of limited re-use strategies. Extended use may also be considered as part of limited re-use strategies whereby an N95 FFR is worn for multiple patient contacts then stored or decontaminated before being re-used. This latter approach is also one supported by Brosseau & Sietsema, (2020), however, they also comment on the fact that prolonged use of the same respirator may have user comfort implications due to a build-up of temperature and humidity inside the facepiece. These extensions of use are related to surge demand and avoiding exhaustion of RPE supply, with CDC stating that the number of times that an FFR can be re-used is limited by:

- Fit
- Filtration performance
- Contamination and soiling
- Damage

The above criteria can be broadly identified in most, if not all, of the published assessments describing the re-use of RPE originally designed to be disposable. Importantly, CDC (2020c) recommend that FFRs visibly contaminated with blood, respiratory or nasal secretions or other bodily fluids should be discarded and not re-used. FFRs that are damaged (for example, broken straps, broken nose piece), malformed, or are unable to pass a fit check are similarly discarded and not re-used.

Several methods are potentially available for decontaminating and, in some cases, sterilizing FFP3 respirators. In order to review each approach a colour coded heat-map was prepared in mid-April 2020 by the Cross-Government PPE Decontamination and Re-use Group (DRG; see Appendix 2). Of the technologies listed, some (in red) were deemed less viable, while others in amber and green were more likely to be safe and effective. Of these, assessments of steam sterilization and hydrogen peroxide vapour for FFP3 respirators are currently a ‘work in progress’. Whilst not necessarily based on the DRG review, these same RPE treatment methods have been considered by several UK and international research groups in recent months and examples of these studies are presented below.

It is important to note that previous VHP/HPV work undertaken in the US did not meet the DRG’s scientific rigour and scrutiny and required additional validation work. Related pilot work is still ongoing at a volunteer Trust in England. This work is aimed at addressing any residual questions from proof of concept work by the DRG. The residual questions are around decontamination cycle validation in different room geometries, efficacy of decontamination on FFP3 respirators in the presence of saliva and hydrogen peroxide off-gassing rates from different respirators. Repeated donning and wear of certain models of respirator is the biggest failure mode.

Decontamination and re-use of disposable filtering facepiece respirators is always likely to be sub-optimal when compared to having an adequate supply of new disposable filtering facepiece respirators. A major failure mode that prevents the re-use of disposable respirators is that many respirators do not stand up to the rigours

of wear and repeat donning and doffing and therefore cannot achieve a subsequent face fit test and may not be suitably protective on subsequent re-use.

Peer reviewed publications about RPE re-use

Bergman, et al (2010) performed quantitative fit testing on three different N95 models before and after multiple applications of ethylene oxide, ultraviolet germicidal irradiation (UVGI), moist heat treatment (MHT) or microwave-generated steam (MGS) to examine the effect of decontamination on respirator fit. Ten test subjects were fit tested on untreated N95s and then on the same sample following one, two and three decontaminations. Respirators were visually examined for degradation following each decontamination cycle. UVGI did not cause any visual degradation, however MHT and MGS degraded one of the three models of respirator where separation of the inner foam nose cushion was evident. Three application of the decontamination methods studied did not cause significant changes in respirator fit. The findings of Bergman, et al. (2010) regarding disposable respirator fit after multiple decontamination cycles were not supported by research undertaken by HSE scientists in support of the NHS.

As an adjunct to the work of Bergman, et al. (2010), it is worth commenting on the potential toxicity of ethylene oxide, since this chemical is commonly used within the healthcare setting, though not for PPE re-processing. Any use of ethylene oxide with RPE is likely to require testing studies to ensure no off-gassing into the breathing zone of the wearer. Kumar, et al. (2020) advise against the use of ethylene oxide for N95 mask decontamination unless advanced testing proves that all traces of ethylene oxide and breakdown products are eliminated.

A 4 year study of FFR treatment with UVGI was undertaken by Heimbuch and Harnish (2019) and numerous usage factors were considered. The experimental decontamination methodology included 15 FFR models, using multiple soiling events with artificial saliva and a skin oil simulant applied to the mask, and optimised the UV dose to reduce the disinfection time. The microorganism studied included Influenza, SARS (severe acute respiratory syndrome) and MERS (Middle East respiratory syndrome) viruses. In addition to the decontamination studies, durability studies were performed by the authors on the 15 FFR models. These involved multiple decontamination cycles to evaluate how UVGI affects FFR straps and FFR filtration component, filtration performance, pressure drop analysis, fluid resistance, and flammability characteristics.

The results were used to develop two standards describing how to evaluate and optimise UVGI decontamination on FFRs for threat agents of interest. For samples of FFR filters treated with SARS MERS viruses, no viable virus was found following a dose of 1 joule per square centimetre (J/cm) of short wavelength (254 nm) UV-C light, even in the presence of artificial skin oil and saliva. The authors also present several useful conclusions for the work:

- UVGI decontamination can be effective against influenza in the presence of soiling agents on N95 FFRs.
- Decontamination can be adversely affected by certain FFR materials (for example, hydrophobic), FFR shapes, and the UV exposure device (for example, UV distribution) if not designed for compatibility with UVGI applications.

- FFRs can withstand multiple cycles of UVGI decontamination without significantly impacting performance, but the maximum level of UVGI exposure allowed will be dependent on the FFR model.
- The repeated act of donning/doffing will likely have more of an adverse impact on FFR performance than UVGI under re-use conditions.
- UVGI decontamination can be effective against multiple influenza and coronavirus strains in the presence of soiling agents on N95 FFRs.
- UVGI decontamination can be performed without significantly impacting flammability or fluid resistance.
- HCWs prefer to keep FFRs for their own use as opposed to sharing.
- HCWs favour having UV decontamination near point-of-care.
- It was noted that FFRs following UVGI treatment contained a singed odour.

Lindsley, et al. (2015) examined the effect of UVGI on the filtration performance, flow resistance and strength of filtering facepiece respirators. Four models of N95 respirators were exposed to doses from 120-950 J/cm^2 and the results showed a small increase in particle penetration (up to 1.25%), but had little effect on flow resistance. At the higher UVGI doses, the material strengths (including straps) were substantially reduced. The authors concluded that UVGI could be used to effectively disinfect disposable respirators for re-use, but the maximum number of disinfection cycles will be limited by the respirator model and the UVGI dose that inactivates the pathogen.

Cramer, et al. (2020a) assessed the treatment of PPE, including 73 N95 masks; five models from three manufacturers. These were evaluated for efficacy of sterilization following treatment using a US-EPA registers process of ionized hydrogen peroxide (iHP; SteraMist®). Treatment efficacy was measured using *Geobacillus stearothermophilus* spore standard biological indicators (BI; Apex). N95 masks were also assessed for their ability to efficiently filter particles down to 0.3 µm and for their ability to form an airtight seal using a quantitative fit test. Filtration efficiency was measured using ambient particulate matter at a university laboratory and an aerosolized NaCl challenge at a National Institute for Occupational Safety and Health (NIOSH) pre-certification laboratory.

The study showed that processed masks retained function for up to five cycles. Masks were placed with their interior surfaces facing up on standard stainless-steel shelves (open grid, InterMetro style). All BIs placed under or adjacent to N95 masks exposed to a single sterilization cycle in the test chamber exhibited at least a 9-log$_{10}$ kill, but pre-treatment with a handheld iHP generator was required for semi-enclosed surfaces for other items, such as respirator hoses.

The authors concluded that a typical iHP environment chamber with a volume of ~80 m^3 can treat ~7000 masks per day, as well as other items of PPE, making this an effective approach. The study was of previously unused N95 masks and the authors acknowledge that additional real-world conditions need to be addressed by future work. This included the question of whether decontaminated N95 masks should be returned to the original users (as specified in Sterrad and Sterris Existing User

Authorisation (EUAs) for N95 mask decontamination) or returned to a common pool (as specified in the Batelle EUA).

The study of Cramer, et al. (2020b) also included an evaluation of gamma irradiation treatment. A set of 3M 8210 and 9105 masks were irradiated using a 60Co irradiator, with the three masks of each type receiving 0 kiloGray (kGy), 10 kGy and 50 kGy of approximately 1.3 MeV gamma radiation from the circular cobalt sources, at a dose rate of 2.2kGy per hour. Following this sterilization procedure, the irradiated masks passed an OSHA Gerson Qualitative Fit Test QLFT 50 (saccharin apparatus) when donned correctly, repeated in triplicate. However, the masks' filtration of 0.3 μm particles was significantly degraded, even at 10 kGy. Separate studies of gamma sterilization have previously been shown as incompatible with polyvinyl chloride (PVC), acetal and polytetrafluoroethylene (PTFE); materials that may be used in various types of RPE and other PPE (Silindir-Gunay & Ozer, 2012). The authors also reported that gamma irradiation is more expensive than the other sterilization methods and requires large facilities. Although Silindir-Gunay & Ozer, (2012) conclude this method to be safe in application, they also emphasised that the effects of radiation on polymers, which can cause material changes and toxic by-product formation, must be evaluated by various analytical methods.

As part of UVc disinfection studies Fisher and Shaffer (2011) reported on a method to assess model-specific parameters for ultraviolet (UVc; 254 nm) decontamination of FFRs. UVc transmittance was quantified for the various composite layers of six N95 FFR models and used to calculate model-specific α-values, the percentage of the surface UVc irradiance available for the internal filtering medium (IFM). Circular coupons, excised from the FFRs, were exposed to aerosolized particles containing MS2 coliphage and treated with IFM-specific UVc doses ranging from 38 to 4707 J/m^2. Respirator models exposed to a minimum IFM dose of 1000 J/m^2 demonstrated at least a 3-log reduction in viable MS2. Model-specific exposure times to achieve this IFM dose ranged from 2 to 266 min. Overall, Fisher and Shaffer (2011) found UVc penetrates into and through FFR materials and log reduction of MS2 was a function of model-specific IFM UVc doses.

Rowan and Lafferty (2020) recently reviewed various aspects of PPE re-use, including the treatment of disposable respirators with germicidal UVc. The authors describe how there have been limited studies on use of UV-disinfection technology but that a previously published study (Bergman, et al. 2010) evaluated a 3-cycle decontamination process for FFRs. The UV irradiation method described was operated for 30 min at 254 nm (15-min/side) for 3M™1860 and 1870 FFRs. They reported that the straps on the 1870 lost elasticity and generated a strong burning odour, and the nose foam was found to compress on 1860 FFR model. Rowan and Lafferty (2020) conclude that prolonged and excessive exposure using low-pressure UV light source can produce significant thermal effects along with material damage over repeated use.

Addendum - updated evidence from pre-publication studies about RPE

The findings of a recent review of RPE re-use by Jena and Sharan (2020) are summarised and included to update this rapid evidence summary originally drafted to support experts advising the UK Government during the COVID-19 pandemic. In

updating the summary of evidence, the authors considered studies as far back as the 1970s including treatments such as bleach and ethylene oxide.

The main conclusions of the review by Jena and Sharan (2020) mirror those reported by the Sage-EMG in early Sept 2020. Briefly, they reviewed 13 different FFR decontamination methods. After considering various factors such as antimicrobial efficacy, effects on filtration performance and fit factor, safety to the users, and cost of a decontamination cycle, they concluded that VHP is the most suitable method. However, it was noted that the high cost and the lack of an FDA-approved VHP machine in most healthcare organization were major challenges to using VHP. The authors also state that germicidal UV could be the next most suitable method for the decontamination of FFRs, with appropriate dose, selection of a suitable FFR model and exposure of full surface area being important for successful decontamination by this method. They also proposed a third more suitable method as the use of dry heat decontamination at 70°C for 30 min. With this method the risk of FFR degradation (melting) still exists, but their assessment of the published evidence suggested this method could be used for up to three decontamination cycles for some FFRs. Microwaving, bleach, ethylene oxide, alcohol, hydrogen peroxide liquid, sanitizing wipes, and soap and water were also considered but were not regarded as effective methods for FFR decontamination.

Another study was published by a Swiss group (Vernez, et al. 2020) soon after the original preparation of this rapid evidence summary. The work assessed the performance of disposable respirators (types 6923 and 1862, 3M, Germany), subjected to germicidal UV treatment using single or successive doses of UV at 60 mJ/cm^2 and following a short drying cycle (30 min, 70°C). The germicidal efficacy of this treatment was tested by spiking respirators with two viral surrogates (bacteriophages vB_HSa_2002 and P66). The respirators were irradiated using multidirectional irradiance delivered using several UVc light sources (n=10) and the presence of reflective walls in the test chamber. Respirator performance was investigated using particle penetration (NaCl aerosol, 10-300 nm), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC) and mechanical tensile tests.

The authors detected no viable phage particles on any of the respirators after decontamination (equivalent to log reduction in virus titre of >3) and no impact on chemical or physical properties was observed (based on SEM particle penetrations were <5-6%). Increasing the germicidal UV dose 10-fold led to chemical alterations of the respirator filtration media (FTIR), but did not affect particle penetration, which remained unaltered even at an irradiation dose of 3000 mJ/cm^2 (50 treatment cycles). When respirators had been used by healthcare workers and undergone decontamination, they had particle penetration significantly greater than unused respirators. Also, wearing of respirators caused a greater decrease in penetration efficiency than the disinfection cycle. Vernez, et al. (2020) concluded that germicidal UV decontamination is an effective method for respirators in cases of extreme shortage, for example, during a pandemic. However, the authors stress that successful implementation would require careful design and particle penetration performance control tests over the successive RPE re-use cycles. This study is in press at the time of writing.

The following section summarises unpublished results from Government and Industry studies of methods to decontaminate/disinfect RPE

Recent HSE Science Division testing studies for respirators

A possible solution to the issue of RPE shortages, as a temporary and emergency remedy, is decontamination and re-use (re-purpose) of RPE designed for single use. However, it is imperative that any re-purposing procedure does not adversely affect the protective nature of the PPE. The cross-Government PPE Re-Use Rapid Review Panel concluded that vaporised hydrogen peroxide (VHP) could feasibly be used to decontaminate disposable FFP3 respirators for re-purposing. VHP is a well-established, commercially available and validated fumigation-based decontamination procedure already in use in some hospitals, for both equipment and whole room decontamination. It was therefore decided that studies should be conducted to investigate the decontamination and potential re-use of a range of single-use FFP3 respirators most commonly used within the UK NHS. At the request of the Panel, a study was conducted by HSE-SD using a VHP system supplied by Bioquell. This research was undertaken by HSE scientists to support the Government PPE Re-Use Rapid Review Panel.

In this study, five models of single use disposable FFP3 respirator were chosen and sourced from the NHS supply chain. Up to ten replicate respirators were placed in a sealable test chamber and decontaminated with either 10 or 20 cycles of VHP using parameters (peak levels of hydrogen peroxide of over 700 ppm) that represent those used for VHP fumigation in NHS Trusts. Unexposed FFP3 masks were retained for comparison. The respirators were placed on a manikin head between cycles to simulate use and were examined periodically between cycles to check for visible signs of deterioration.

Stainless steel discs, onto which were immobilised biological indicators (*Geobacillus stearothermophilus* spores), were inserted into the fabric of duplicates of the respirators set aside for this purpose. This was to assess the effectiveness of VHP and determined as log reduction in spore numbers compared to unexposed controls, in penetrating the respirator material and killing microorganisms present. Fumigated FFP3 respirators were tested for any detectable residue of hydrogen peroxide within the respirator material. Filter penetration tests were conducted to determine whether fumigation affected filter integrity and standard fit testing using human volunteers was conducted to compare unexposed FFP3 masks with those fumigated for 10 or 20 cycles.

A 4-6 log reduction in viability of bacterial spores inserted within the material of the respirators was achieved in most cases in repeat decontamination cycles for all makes and models of respirator tested in this study. Visual inspection of the decontaminated respirators did not reveal any deterioration likely to have been caused by repeated exposure to high levels of VHP. Minor defects were observed in a small number of respirators, but these were thought likely to have been the result of simulated repeat wear.

Off-gassing measurements of hydrogen peroxide from the decontaminated respirators revealed levels above the Workplace Exposure Limit some hours after a period of aeration, suggesting a need to ensure sufficient aeration is done before

respirators are bagged up and returned to wearers. All FFP3 masks passed filter penetration tests mostly well within the required maximum of 1%, with no strong evidence of sequential deterioration with multiple cycles of VHP fumigation. Although based on only a small number of replicates, there was little evidence of any progressive decline in fit test performance with fumigated FFP3 masks.

The small-scale study by HSE-SD demonstrated the feasibility of effectively decontaminating FFP3 respirators using a VHP fumigation system. On this basis, a pilot scale exercise was conducted using a similar VHP fumigation system at a hospital in Nottingham using FFP3 masks previously worn by HCW with the objective of being able to return them to the original wearer for repeated re-use.

In research to support the NHS COVID-19 pandemic response HSE scientists quantitatively tested five respirator models on 25 fit test volunteers. Respirators were fit tested before use and after 10 and 20 cycles of vaporised hydrogen peroxide decontamination. Three of the five respirator models saw reductions in fit test values after decontamination and showed a greater reduction after 20 decontamination cycles compared to 10 decontamination cycles. However, these reductions were statistically significant for just one respirator model, which saw a 47% reduction in fit test value after 10 decontamination cycles and a 53% reduction after 20 decontamination cycles compared to respirators that had not been decontaminated. The authors advise that care should be taken not to over-interpret differences that were not statistically significant. Due to the variability in fit test values and the relatively small number of volunteers involved, the change in fit test value would need to be relatively large to be (statistically) detectable. A non-significant result in this circumstance is not reliable evidence that the fit test values did not change.

NHS RPE testing during the Sars-CoV-2 pandemic

Based on work completed to date by NHS Scotland and NHS Wales, two models of 3M FFP3 tolerated autoclave treatment at 121°C for 15 minutes and retained the ability to achieve a fit test on the same person without the filtration penetration being adversely affected. This is only suitable for 1 cycle of decontamination, which would allow one re-use. Advice from a HSE expert is that respirator degradation and reduction in filtration penetration are the biggest failure modes after autoclaving at 121°C.

Planned/on-going Government funded RPE testing work

NHS England is currently designing a pilot study investigating the potential re-use of FFP3 respirators using hydrogen peroxide vapour (HPV) decontamination.

Public Health England and HSE are acting as technical consultants in designing the study. Practical work has not yet started at the time of reporting (w/c 17.08.20) but the aim of the study is to provide a good evidence base to ensure:

- Efficacy of decontamination is proved
- Any fumigant off-gassing returns to a safe level before re-use
- A combination of HPV and multiple user wears does not affect the fit of the respirator.

Each make and model of respirator must pass the above criteria. Once a respirator has passed all aspects of the study knowledge will be held and implementation considered in the event of an emergency or if the supply chain cannot cope with demand.

RPE work involving UK industry suppliers and the NHS

Vaporised hydrogen peroxide:

Another use of hydrogen peroxide (H_2O_2) vapour as a fumigant has been the ProXcide Vaporised Hydrogen Peroxide (VHP) technology system developed by Inivos. It uses ultrasonic vaporisation technology to create microscopic droplet sizes of H_2O_2 that are forced-evaporated to create H_2O_2 vapour. It has been validated for decontamination of room surfaces and contents, shown to provide a 6-log reduction in microorganisms on surfaces.

Inivos has recently developed a modular decontamination chamber system, the ProXpod, suitable for local decontamination of PPE at hospital sites to provide a contingency solution to supply chain shortages. In summary, ProXpod comprises a portable 2.4 x 2.4 x 2.1 m sealable pod that can be set up within a hospital/healthcare setting and incorporating their H_2O_2 vapour system (see Figures 1a and 1b). The pods are configured with wire racks on which to position PPE items for fumigation and proof of concept projects have been conducted at Southampton and Cambridge using FFP3 respirators. Pre-processing selection criteria determined that only suitable FFP3 respirators would undergo the decontamination process, for example respirators containing cellulose-based or paper materials were excluded due to incompatibility, and compatible respirators had to be free of visible damage and soil/contamination (for example, blood, dried sputum, other bodily fluids or makeup). Seven FFP3 respirator makes (3M 8833; 3M 1863; 3M 1863+; MEDLINE NONE24510VF; EASIMASK FSM16; JSP232; EASIMASK FSM18) were used. In excess of 400 used FFP3 respirators meeting the selection criteria were sourced from fit testing exercises and non-COVID-19 theatres (intact masks) and placed on the wire shelves.

Surrogate efficacy tests (standard *Geobacillus stearothermophilus* spore-based biological indicators (BIs) and chemical indicators (CIs) were defined on the principle that the BIs would be more resistant to disinfection than the SARS-CoV-2 virus and would demonstrate efficacy under worst-case criteria, while CIs would demonstrate gas penetration. The assumption was that if CIs reacted as expected and BIs confirm efficacy, the CIs (which provide fast response data compared to BIs which take at least a day for results) alone could be used as quality control measures in further decontamination cycles.

Figures 1a and b. Inivos hydrogen peroxide fumigation system (left) in use to treat respirators; portable treatment facility right.

The VHP decontamination cycle efficacy test was carried out using standard BIs and CIs to indicate successful decontamination in worst-case locations, for example, corners, of the ProXpod. No growth was recorded after 7 days incubation on any exposed BIs after decontamination cycles, only on unexposed positive controls. All Cis, except for negative controls, had turned green indicating full H_2O_2 exposure. Both results thus demonstrated successful decontamination across different parts of the ProXpod decontamination chamber achieving >6-log spore reduction.

Of the total number of FFP3 respirators decontaminated, 72 representing all types were inoculated with 1.8 x 10^6 *Geobacillus stearothermophilus* spores in aqueous suspension. Therefore the same organism was used at similar concentration as in the standard BIs used to assess survival post-decontamination in different layers and parts of the respirators. For worst-case placement of CIs on each wire shelf, one was placed inside a respirator openly exposed and a second placed inside a folded respirator or in the respirator foam fold therefore not openly exposed. For respirators with vents a CI was folded and placed inside the vent area. No growth was recorded after 7 days incubation following the VHP decontamination cycle for any of the 72 FFP3 respirators that had been inoculated with the spore solution, growth only occurring on positive controls. All CIs except for negative controls, including those visibly exposed and those placed inside folded respirators, or in the respirator foam fold, had turned green indicating that H_2O_2 gas had penetrated filter material exposing surfaces that are visually covered.

A PortaSens H_2O_2 gas monitor was used to detect off gassing from respirators. Readings were taken immediately after the process as soon as the ProXpod could be re-entered (<2 ppm H_2O_2). FFP3 respirators were then taken out of the ProXpod and moved into a well-ventilated area and monitored periodically until H_2O_2 gas levels dropped below detectable levels. The results demonstrated that all models of FFP3 respirators required extra time to off-gas residual H_2O_2 gas after the VHP decontamination process. However, no H_2O_2 was detectable after overnight off-gassing suggesting this to be sufficient although further testing was recommended to ensure that H_2O_2 off-gassing levels reach a safe level before respirators can be re-donned.

Standard volunteer fit testing was carried out for two types of FFP3 (3M 8833 and 3M 1863), fit testing being conducted before and after 5 cycles of VHP on 10 respirators of each type. Fit test results for 3M 1863 FFP3 respirators indicated no

significant change in fit score after 5 VHP decontamination cycles compared to unexposed. While the fit test results for 3M 8833 FFP3 respirators, before and after 5 VHP decontamination cycles, indicated a change in fit score result, all achieved the overall score of greater than 100 to pass the test. Individual volunteer scores suggested their overall scores had been impacted mostly by the last three of the standard tests (talking aloud, bending over, and the final normal breathing).

Standard performance tests conducted on six of each type of FFP3 respirator (three of each as unexposed controls and three exposed to no less than five VHP decontamination cycles) included visual inspection, penetration of filter material, and breathing resistance. All respirators were marked with a unique respirator tracking number and the test laboratory was not informed which respirators were exposed to the VHP cycles to constitute a blind test. All types of respirator passed the performance tests, maintaining required parameters after being exposed to VHP.

The above proof of concept results provided sufficient evidence of efficacy to proceed to a pilot scale study being undertaken at Addenbrookes Hospital Cambridge.

Unpublished international research related to RPE

Whilst updating of this rapid evidence summary, additional unpublished scientific information was shared by UK and international research groups. This comprised information from studies undertaken since the start of the Sars-CoV-2 pandemic. The unpublished UK data are summarised in this document but the results of some other international studies were not included as the authors intend to publish their findings separately.

Eye protection

Face visor construction materials, other than any elasticated securing fixtures, could be made re-usable, but most are discarded after single use. The materials of construction will ultimately determine how easy they are to clean and disinfect, also the resources available, especially in the healthcare setting, to achieve effective reprocessing of these items. Some manufacturers are now aware sustainability is a important consideration for the NHS and are designing products that can be easily cleaned and disinfected for multiple cycles. The biggest challenge is usually around overcoming existing infection prevention and control instructions, which may not always be compatible with re-use. The challenges around eye protection are covered elsewhere in this document, under the section re-usable PPE eye protection.

Disposable gowns/over suits

Published studies

Compared to RPE, the available pre-COVID19 reprocessing data for gowns and other forms of body covering are limited and much of the available data has been generated from recent mostly unpublished studies. The published evidence is as follows:

Saini, et al. (2020) also reported the use of vaporised hydrogen peroxide (VHP) for the treatment of coveralls. The study assessed treatment efficacy, which was successful in reducing multiple bacterial challenges, including spores, by between 6-

and 7-$\log_{10}$. The authors also used material integrity testing for coveralls - permeability and deformation assessments – as a measure of treatment impact. Water drops of 50 and 100 µl volumes were randomly spotted on the coveralls on high exposure areas and used to calculate the time of permeation through the fibre. This process is not a standard permeation test but was normalised to take account of normal evaporation processes. Scanning electron microscopy was also used to compare test materials with untreated controls, to assess material integrity and deformation of fibres.

No significant change in the permeability of droplets on various coveralls was noted. In addition, the integrity of the coveralls showed no discernible change following VHP and an additional hypochlorite treatment. The latter was described by the authors as essential to remove stains of body fluids post-VHP disinfection, but it is unlikely that such soiled items would ever be re-used in this way in UK workplaces. Saini, et al. (2020) reported that VHP treatment did not cause any significant alteration to the microscopic structure of coverall materials, even when repeated cycles (n > 15) of VHP treatment were used, concluding that VHP is suitable as a method for this type of disposable PPE disinfection.

Cramer, et al. (2020a) assessed the treatment of an assortment of PPE using in ionized hydrogen peroxide system (iHP, generated by SteraMist® equipment). A limited assessment of one type of a Tyvek suit was included in the study and was treated with fumigant hung in various configurations within a purpose-designed chamber. BIs were placed on surfaces that were judged least accessible to the fumigant. The 100-minute sterilization cycle in the chamber included: an initial 15-minute delivery phase (mist release); a 20-minute dwell phase (mist to penetrate); a 65-minute removal/aeration phase (exhaust re-opened to aerate the space @ 43 air changes per hour). The study found that such equipment could be sterilized by this process, but only when pre-treatment was employed with a handheld iHP-delivery device, followed by a cycle of iHP treatment in the chamber. Sterility was measured by a minimum 6-$\log_{10}$ reduction of *Geobacillus* bacterial spore preparations.

Other government advice

Public Health Ontario (PHO, 2020) has published a report about the re-use of Personal Protective Equipment. They cite CDC (2020d) guidance in relation to re-use of otherwise disposable protective gowns, stating that "*.easy breakage of disposable gown ties and fasteners makes them less amenable to washing and re-use than re-usable gowns*". When disposable gowns are in short supply, CDC suggests a number of alternatives, for example, extended use of gowns; using reusable (washable) patient gowns and laboratory coats. Similar extended usage advice is provided by PHE/Gov.UK (2020) but is called 'sessional use'.

Specifically, CDC (2020d) states that re-usable (i.e. washable) gowns are typically made of polyester or polyester-cotton fabrics. Gowns made of these fabrics can be laundered without compromising their integrity by following routine procedures for re-use. However, the advice states that care should be taken to ensure that the healthcare worker does not touch outer surfaces of the gown during care. Systems also need to be established to routinely inspect, (and repair if necessary), or replace reusable gowns when needed, such as when they are thin or ripped. CDC (2020d)

guidance also states that the same isolation gown (disposable or cloth) can be worn by the same healthcare worker when interacting with more than one patient infected with the infectious agent/disease in the same location (for example, COVID-19 patients residing in an isolation cohort). CDC emphasises this can be considered only if there are no additional co-infectious diagnoses transmitted by contact (for example, *Clostridium difficile*) among patients. If the gown becomes visibly soiled, CDC guidance indicates that it must be removed and discarded.

With regard to cloth isolation gowns only, CDC (2020d) recommends that where the gown is being used as part of standard precautions to protect a healthcare worker from a splash, the risk of re-using a non-visibly soiled cloth isolation gown "*may be lower*". However, for care of patients with suspected or confirmed COVID-19, *".risk from re-use of cloth isolation gowns without laundering among (1) single workers caring for multiple patients using one gown or (2) among multiple workers sharing one gown is unclear. The goal of this strategy is to minimize exposures to healthcare professionals and not necessarily prevent transmission between patients. Any gown that becomes visibly soiled during patient care should be disposed of and cleaned*."

UK Sars-CoV-2 studies on reuse of single use PPE

North of England pilot study – re-use of single use gowns

In a North of England pilot study, an NHS Trust contacted HSE Science Division (HSE-SD) concerning a programme of work to evaluate the performance of single-use surgical gowns and coveralls after they have been subjected to a number of wash-cycles. The rationale: to determine the number of wash cycles at which garment performance becomes degraded would enable the Trust to develop guidance on the maximum number of wash cycles that should be applied to provide appropriate reassurance to wearers in a garment's performance after washing.

A range of surgical gowns, each previously subjected to up to four standard hospital wash cycles, were provided by the Trust. In addition, some unwashed gowns made bespoke for the Trust by local manufacturers were tested. All were compared with new gowns provided by HSE-SD as control samples. After initial visual examination, the material configuration in each garment/ wash-cycle combination was evaluated using optical microscopy and any features noted. Following this, each garment was spray tested using an adaptation to the nominal requirements of BS EN ISO 17491-4:2008. This method uses a fixed spray configuration to expose gowns mounted on a manikin to continuous jets of water for a specified time. An absorbent layer is placed on the manikin under the test material and a fluorescent dye was used to indicate liquid penetration, with the absorbent material viewed and photographed to qualitatively and semi-quantitatively determine the extent of liquid penetration resistance for each gown.

Visual examination showed different types of garment sewing techniques used included knitted plain seams, plain seam with double top stitch, ultrasonic seams or stitch sewing. Overall, the gowns appeared to be in a relatively good condition, although gowns manufactured with knitted/stitched seams showed some potential weakness in terms of fluid protection as small holes were observed along the seam.

In initial series of tests on non-woven fabric gowns from recognised hospital PPE suppliers, four out of five gowns after washing showed little or no evidence of

material penetration when challenged with a spray compared to material penetration in the equivalent new unwashed surgical gowns. By contrast, a bespoke gown made of woven material showed evidence of extensive fluid penetration through the gown material.

In a second series of tests to support the NHS COVID-19 reponse, HSE scientists examined seven gowns supplied from recognised hospital PPE suppliers. After washing them three times, they showed little, or no, evidence of material penetration when challenged with a spray. They compared well to a new unwashed surgical gown. By contrast, either unwashed or washed once bespoke gowns, again made of woven material, showed evidence of extensive fluid penetration through the gown material.

In conclusion, this limited study indicated it would be feasible for recognised brands of single use surgical gowns to be laundered for re-use and still provide spray protection, but some gowns being sourced locally by hospital Trusts do not meet the required standards of protection even before laundering.

Inivos vaporised hydrogen peroxide reprocessing of single use PPE

A joint collaboration to assess the re-use of single-use PPE garments, prompted by recent shortages of items such as surgical gowns and coveralls, was undertaken University Hospital Southampton (UHS) and Inivos Ltd. Additional technical support was provided by Wessex Academic Health Science Network, to develop a validated protocol PPE garment re-use.

In summary, a wash/detergent cycle at 30^0C followed by cool tumble drying, achievable at UHS, renders garments physically clean, does not compromise the integrity of garments providing tumble drying is not excessively hot or lengthy, and is thought to be sufficient for viral inactivation, but the latter is unproven and difficult to demonstrate. The NHS-recommended laundry cycle (HTM 04-01), expected to deliver effective decontamination, may damage some single-use garment types by affecting permeability. By contrast, evidence from previous work suggests exposure to vaporised hydrogen peroxide (VHP) would be highly effective at reducing viral contamination (and other microbiological bioburden) to zero, but is less effective if organic matter is present and will not render garments physically clean. A combination of physical washing with detergent and tumble drying followed by exposure to hydrogen peroxide (H_2O_2) was considered to be the most likely to be effective for both viral decontamination and physical cleaning, leading to a study by the above collaborative partners.

To test the above hypothesis, a sealable chamber was set up with the capacity to process up to 100 single use coveralls made from liquid-impermeable coated fabric with elastic cuffs at wrist and ankle, zipped front, taped seams and elasticated hood. Two test runs were conducted. For Run 1, a biological indicator (BI) comprising a spore culture of *Bacillus oceanisediminis* was prepared by UHS microbiologists. For Run 2, this BI was again used and *Staphylococcus aureus* and *Klebsiella pneumoniae* were also added. The spore BIs present a worst-case challenge, being more resistant to H2O2 decontamination than viruses, and the other two bacteria represent typical human commensal bacteria that might be present as bioburden on a worn coverall.

The BIs were inoculated onto three garments taken from each batch, sited under one arm of each test garment on the outside surface to represent a worst-case position, at concentrations ranging from $2.0x10^4$ to $2.0x10^7$ then replaced in the load. These garments were placed in the load at what was considered to be a worst-case location for gas exposure. H_2O_2-sensitive chemical indicators (CIs) were placed throughout the load, including facing the H_2O_2 generator as best-case positions as positive controls, and at expected worst-case positions based on garment spacing, movement in air-flow, and distance from the generator, including inside garments. After each H_2O_2 decontamination run approximately 50min of fresh air ventilation was incorporated, then nine garments from each run were selected and tested for residual levels of H_2O_2.

For Run 1, the H_2O_2 cycle was successfully completed although two additional extract cycles were found to be required to reduce residual H_2O_2 to safe levels taking the total cycle time to almost three hours. Microbiological analysis yielded bacterial growth from the test garments, but these bacteria differed from the spore BI used as an inoculum. It was concluded that the decontamination method successfully killed the BIs but there was growth of environmental organisms entrained during the sampling process, possibly from open windows and the door to the hospital corridor before and during sampling, or from the clothing/skin of the microbiologist taking the samples. CI tests mostly indicated there had been full exposure correlating to biological decontamination, but one CI was not fully exposed. This usefully demonstrated that the CIs were sensitive to different levels of H_2O_2 exposure, i.e., do not react immediately at the lowest level, and were therefore suitable to be used as a QC indication in each cycle, but that Run 1 had not been optimal, thus requiring repeat testing.

For Run 2, the same H_2O_2 parameters and similar CI locations as Run 1 were used, but garments tested were divided into three tests, either wash/dry only (garments not exposed to VHP), VHP only, or wash/dry and VHP. In total, 78 garments were submitted to VHP treatment. The use of additional fans aimed to improve H_2O_2 circulation, and BIs were inoculated on the chest and front of leg of the test garments, representing likely highest exposure in clinical use and therefore highest bioburden for the sanitisation process. Improved aseptic and environmental control precautions were employed to try to prevent environmental contamination during sampling post-VHP.

Again the cycle duration and parameters indicated successful completion, and CI tests showed improved and satisfactory gas distribution had been achieved from using the additional fans to overcome the challenges of the higher load density.

BI tests showed that, as with Run 1, there was significant growth in some samples. It was concluded that garments processed only by washing showed substantial bacterial contamination. For garments only processed with VHP, post processing *Staphylococcus aureus* was recovered in 2% of samples, i.e., the same organism as inoculated. For garments with wash+VHP, no inoculated organism was cultured after processing, suggesting any bacteria recovered were environmental contaminants from the sampling process.

Garment integrity tests comprised visual examination and in-house spray challenge tests to look for breakthrough as shown by damp patches on scrubs worn underneath. No integrity problems were identified.

It was concluded that:

- VHP reached all areas of the chamber, as shown by CI results, indicating that with revision a suitable loading pattern was achieved and that cycle parameters showed the process to be reproducible.
- Garment integrity was not affected by the process (single cycle).
- No VHP was detected outside the processing room, and effective end-of-cycle removal of H_2O_2 residues from environment and garments was demonstrated, indicating process safety.
- Reprocessing by laundering followed by VHP exposure achieved satisfactory standards of disinfection, based on limited microbiology testing using organisms considered to be worst-case surrogates for SARS-CoV-2, including successful removal of heavy inoculum of *Staphylococcus aureus*, *Klebsiella pneumoniae* and *Bacillus oceanisedemenis* spores.
- The results therefore provided reasonable assurance this method would remove SARS-CoV-2 from the garments tested.
- Non-pathogenic environmental organisms identified in the garment samples were of no clinical significance and thought to originate from the sampling process.
- Because of the environment where this process is conducted and post-cycle presence of environmental organisms, the method can achieve sufficient decontamination of PPE garments to be used in clinical areas but that these should not be used for sterile process, for example, theatres.

Subject to Trust approval it was to be developed into operating procedures within UHS Sterile Services for PPE garment reprocessing in the event of supply chain failure. It was considered that the process could be transferred to other centres, provided prior qualification of local conditions was undertaken with this study providing a basis for such qualification. It was recognised that the work had low statistical power and only tested one garment type (brand), but was promising and with a 3hr cycle time gave capacity for reprocessing around 450 garments per day. Although that was well below the daily demand for PPE garments at UHS, it would offer some relief to demand.

International advice about reuse of disposable gowns/over suits

The US Association of Linen Management (ALM) undertook a study of three types of used disposable protective gowns, which were procured directly from a regional healthcare system. The gowns used in the assessments were categorised as medium light soiled, but not blood soaked or heavily soiled. Specifically, the test items comprised:

- Polyethylene Thumb Loop Isolation Gowns (blue); the material only passes ASTM F1670 synthetic blood penetration tests and was sold in bags of 15. Five gowns were included in the trial load.

- Non-Reinforced Surgical Gowns with critical zones for front chest, sleeve, sleeve seam and front belt attachment point, blue spunbond-meltblown-spunbond (SMS), non-woven, polypropylene fabric with polyester cuffs, AAMI Level 3. Three extra-large gowns were included in the trial load.
- Sterile Polyethylene-reinforced front and breathable film sleeve gowns with hook & loop closures (blue); AAMI Level 4. Twenty-two large gowns were included in the trial load.

The test items were processed using a gentle washer-disinfector cycle and high-water levels to inhibit mechanical action and to maintain the integrity of the gowns. Wash cycle temperatures of up to 104^{o}C were used, along with enzymatic cleaning fluid and a 'finish' sanitiser containing a quaternary ammonium compound. The gowns were then dried using a tumbling process to allow trapped water to drain and examined for their overall condition, the effectiveness of the wash formulation, and effects of the washing process on the gowns.

The study found that although some gowns used in the trial process contained polyurethane this did not appear to be affected by the wash process. However, the author states that it is important to closely manage dryer temperatures with these products; a maximum temperature of 120°F is desired to avoid destruction of the gowns. Other findings included that the PPE gowns manufactured as an AAMI level 3 or 4 barrier gown held up best in the wash process. However, these are manufactured for a single/one-time use at that level and the authors conclude it is unlikely – under US requirements at least - that laundries could determine the suitability of these reprocessed PPE for further use at that level.

Importantly, no final re-waterproofing of the garments was performed but the study stated this is an option that a laundry can choose to add this treatment in the final rinse. The limitations of this work are clear and the study stated, "these gowns, *although intended for single-use, have been reprocessed and no claims can be made as to their protection abilities i.e.,* ***they should not be used as PPE***".

The US-CDC (2020d) provides advice for the re-use of different types of gown. They state that disposable gowns are not typically amenable to being doffed and re-used because the ties and fasteners typically break during doffing. CDC (2020d) advise that cloth isolation gowns could potentially be untied and retied and could be considered for re-use without laundering in between. However, for care of patients with suspected or confirmed sars-CoV-2 infection, the CDC concedes that the infection risk from re-use of cloth isolation gowns without laundering is unclear. They indicate that goal of this strategy is to minimize the exposures of the healthcare worker and not necessarily to prevent transmission between patients. As with other PPE advice, it is recommended that any gown that becomes visibly soiled during patient care should be disposed of and cleaned.

Disposable aprons

Generally, these are not re-used as typical infection prevention and control measures involve snapping the straps during doffing. This is the easiest way to doff without creating a cross-contamination risk to the wearer or others and renders the item unusable thereafter.

Gloves

Work in this area was discussed by the NHS Infection Prevention and Control cell, and focussed on prevention of over-use of the existing glove stock (evidence communicated to HSE). This work stream was not taken forward as it was not deemed a realistic proposition. One option for re-use was to extend the usage of gloves during shortages by potentially disinfecting with a dilute (0.5-1%) sodium hypochlorite solution between patients. There was some scepticism regarding how practical this was for healthcare workers on a busy COVID-19 ward. Concerns were also raised around storage of the bleach solution and contact and drying times thereafter, as well as the increased risk of skin damage and skin conditions to the healthcare worker.

5. Face coverings (not classed as PPE)

5.1 Clinical settings

Within the peer reviewed literature, one cluster randomised study investigated the comparative efficacy of cloth masks and surgical masks in the clinical setting (MacIntyre, et al. 2015). Participating healthcare staff on seventy-four wards - emergency, infectious/respiratory disease, intensive care and paediatrics – were regarded as working in high-risk settings for occupational exposure to respiratory infections. 1607 healthcare workers (an 86% participation rate) working in one of 14 hospitals in Hanoi were randomised to; constant medical mask wearing, constant cloth mask wearing or usual clinical practice. The main outcome measures of the study were:

- clinical respiratory illness (CRI),
- influenza-like illness (ILI) and
- laboratory-confirmed respiratory virus infection.

Participants were instructed to wear their designated mask on every shift for four consecutive weeks. Participants in the medical mask arm were supplied with two masks daily for each 8 h shift, while participants in the cloth mask arm were provided with five masks in total for the study duration, which they were asked to wash and rotate over the study period. They were asked to wash cloth masks with soap and water every day after finishing the shifts and were supplied with written instructions on how to do this. Masks used in the study were locally manufactured medical (three layer, made of non-woven material) or cloth masks (two layer, made of cotton) commonly used in Vietnamese hospitals. The control group was asked to continue with their normal practices, which may or may not have included mask wearing. Mask wearing was measured and documented for all participants, including the control arm. Rates of influenza-like illness were highest in the cloth mask arm (RR 13.00 [1.45 – 28.65] when compared to medical masks and RR 3.49 [1.00 – 12.17] when compared to control). Supporting mask filtration tests showed that the penetration of particles through the cloth masks was high (97%) compared with medical masks (44%) used in trial and 3M 9320 N95 (<0.01%), 3M Vflex 9105 N95 (0.1%).

In a 2020 opinion piece, the same authors – MacIntyre, et al. (2020) - offered the following comments regarding utilisation cloth masks in the current healthcare setting: "*We recommend that health workers should not work during the COVID-19 pandemic without respiratory protection as a matter of work health and safety. In addition, if health workers get infected, high rates of staff absenteeism from illness may also affect health system capacity to respond. Some health workers may still choose to work in inadequate PPE. In this case, the physical barrier provided by a cloth mask may afford some protection, but likely much less than a surgical mask or a respirator.*" (MacIntyre, et al. 2020).

The European Centre for Disease Prevention and Control (ECDC) advises against use of cloth masks in the clinical setting, as penetration of viral particles is significantly higher than when wearing surgical masks. Specifically, ECDC states

that common fabric cloth masks are not considered protective against respiratory viruses and their use should not be encouraged. As such, they do not provide any guidance for cleaning of cloth masks in the clinical setting (ECDC, 2020b). Within this report, ECDC also refer to CDC guidance in this area. The CDC only recommends the use of cloth facemasks in a clinical setting as a last resort when surgical masks are not available and that these should ideally be used in combination with a face shield. This guidance also provides no advice on washing/re-use (CDC, 2020e).

5.2 Community settings

There is little data surrounding use or re-use of cloth masks in the community setting. Numerous journalistic sources aimed at the general public advise washing of masks after use, however guidelines about frequency and method of washing vary between sources.

John's Hopkins Medicine, (2020) recommend washing after every period of use. However, the UK government do not give specific recommendations on frequency, instead recommending that people should '*wash it in line with manufacturer's instructions at the highest temperature appropriate for the fabric'* (Gov.uk, 2020b).

The CDC (2020f) provides advice to the public about face coverings, much of it in simplified and in pictorial form, including basic information on how to choose, remove and wash the item. CDC (2019f) states this can be done either by hand or in a washing machine. Machine washing suggests putting the 'mask' with other regular laundry, using regular laundry detergent and the warmest appropriate water setting for the cloth used to make the mask. The CDC hand washing method recommends the use of bleach intended for disinfection purposes rather than textile bleaching agent (5.25%–8.25% sodium hypochlorite). It also advises avoiding this method if the hypochlorite is not available in this concentration range or if bleach is not compatible with the textile used to make the face covering.

6. Behavioural responses to re-used PPE

Published evidence about the psychological and behavioural aspects of PPE re-use is scarce. The NEPC (2020) draft commentary acknowledges that ‘confidence’ in PPE reprocessing was identified as a factor in its cited case studies. This confidence was associated with rigorous testing of the PPE treatment protocol. This commentary also highlighted that, for hygiene reasons, re-used respirators need to be identified and returned to the same user after reprocessing to meet acceptability of re-use.

A 4-year study of the re-use of FFR by Heimbuch and Harnish (2019) included a questionnaire in which health care workers were asked about mask re-use and their preferences related to the process. The authors reported that the major preference was that re-used FFRs are retained for personal use not sharing.

The National Nurses United (NNU), the largest labour union for registered nurses in the US, published its concerns about their members having to wear re-used N95 RPE. They concluded that the system developed by Battelle cannot be both safe and effective (NNU, 2020).

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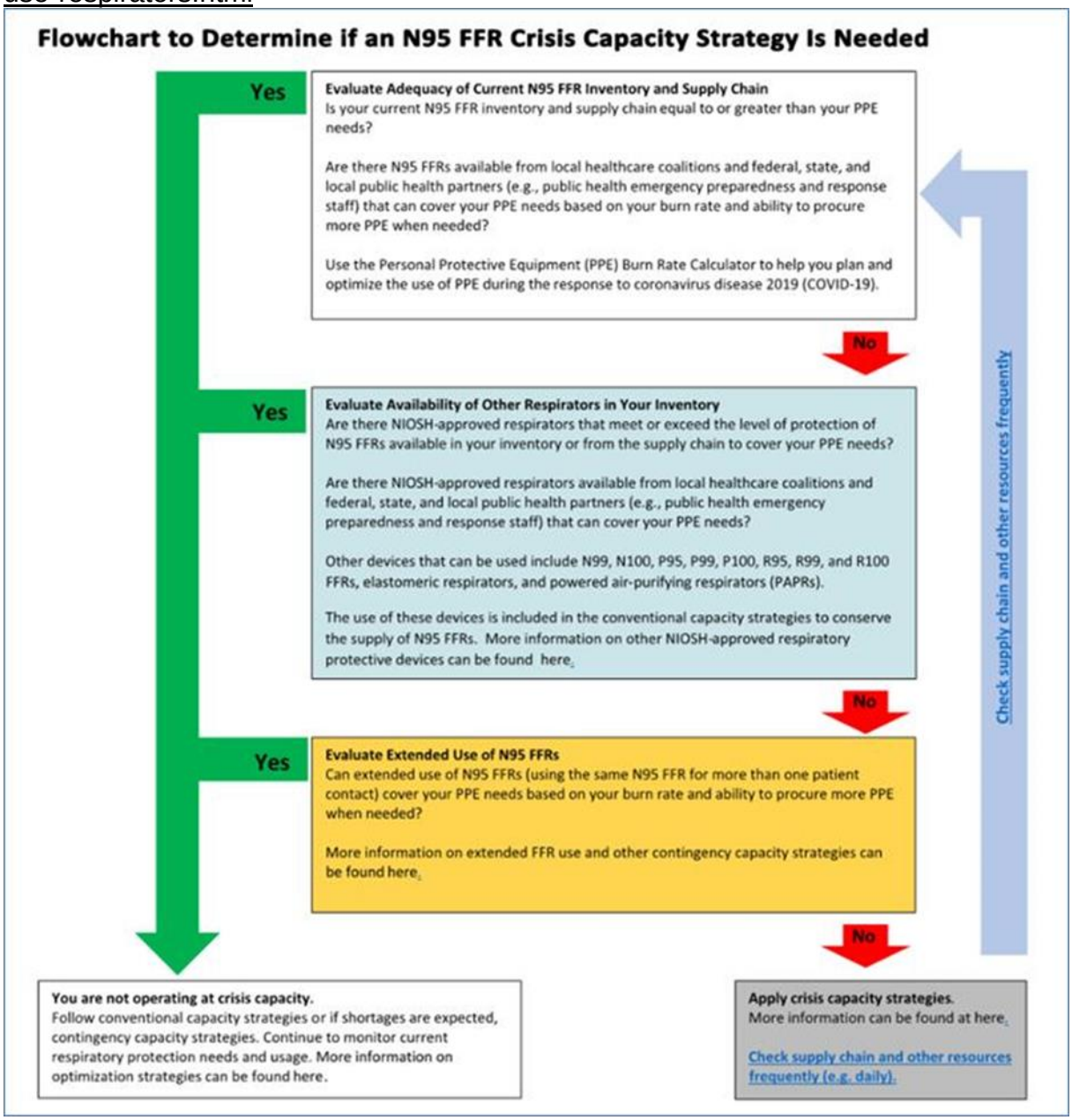
Appendix 1. CDC flowchart for RPE re-use

From an N95 resuse decision process published by the US CDC, 2020, https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-re-use-respirators.html



Appendix 2. PPE Decontamination heat map

Heat map devised in mid-April 2020 by the Cross-Government PPE Decontamination and Reuse Group (DRG)- considering different decontamination technologies for re-using respiratory protective equipment

Assessment criteria	HPV (centralised solutions) Battelle or Bioquell	HPV (localised solution) VPro/Sterad	Steam	UV light	Ozone	Ethylene oxide
Performance	• Testing available so far suggests effective sterilization. Concerns about FIT. Mask need to be returned to original user • Battelle system FDA exemption provided in US for N95 masks	• Testing available so far suggests effective sterilization. Concerns about FIT. Mask need to be returned to original user	• High steam – v effective sterilization but concerns around damage to mask FIT. • Lower steam – less effective sterilisation but less damage to FIT	• Some concerns around performance that need further testing	• Limited scientific evidence or testing available	• Effective at sterilization. Unclear about FIT
Longevity	• <12 re-uses	• V-Pro 10 re-uses • Sterrad <2 re-uses	• 1-2 re-uses	• >10 re-uses	• Unknown	• 3 re-uses
Safety and environmental concerns	• No environmental concerns • Off gassing required	• No environmental concerns • Off gassing required	• Minimum concerns. Existing technology with minimal residues	• Some safety concerns Depends on if a room contained or self-contained system	• Ozone highly reactive and toxic	• Concerns around carcinogenic residues being left, particularly with Masks
Logistics, scalability and implementation	• Require shipping from US (Battelle) but staff, equipment etc. all come with it vs already available in via Bioquell	• Some staff trained locally at sites but would need to increase that	• Relatively easy to scale as steam sterilisations exits within most hospitals • Need work to adjust cycles of sterilisers for this purpose and relevant training for staff	• Require working with manufacturers to develop a bespoke scaled room solution but possible in weeks	• Single unit proposed to be operational by June. Unclear on further units	• Site in Scotland.
Applicability to different loads	• Battelle are currently testing this in the US. Awaiting results • Incompatible with cellulose	• Unknown • Incompatible with cellulose and nylon	• Unknown	• Unknown	• Large numbers of material compatibility concerns raised	• Could be used for gowns already used for medical devices
Types of costs involved	• Depends on the manufacturers for example, .Battelle offer would require procuring from US, flying over and would come with all the staff, kit etc. • Bioquell offers a UK based solution but costs unknown	• Only available in a limited number of local sites currently, so additional costs to expand to more sites	• Existing technology onsite, so training mainly, repair costs from increased used	• Scaling up a new bespoke solution	• New approach proposed by company £50-60k per unit	• Unknown
Further work	• Performance validation testing • Further detailed work to understand and compare the differences between the two manufacturers' offering. • Develop feasible implementation roadmap	• Performance validation testing • Understand trade-offs compared to centralised system • Develop feasible implementation roadmap	• Performance validation testing • Work with manufacturer to determine cycle testing • Develop feasible implementation roadmap	• Performance validation testing • Work with manufacturer to develop bespoke room-based solution and understand availability of units in the UK • Develop feasible implementation roadmap	• No. Only evidence based on submission from potential supplier. Enough concerns over the effectiveness, longevity and safety to rule out	• No. Significant concerns writ to re-using masks. Could be considered for wider PPE such as gowns.

Appendix 3. Literature search methodology

1) How this rapid review of evidence was prepared

Literature search: Published literature searches were based on specific key search words that related to the original research request (see Table below). This provided a focused approach but one that was not likely to exclude important papers. The information systems analyst who performed the searches was also well briefed on the topic to allow iterative/adjustments to the searches, in particular to help exclude non-relevant material. The search period included publications between Jan 2000 and August 2020, thus incorporating relevant studies related to Sars-CoV-1 and MERS, as well as the recent Sars-CoV-2 pandemics.

The searches for peer-reviewed studies were undertaken using the search engines Web of Science™, EMBASE™ and PubMed™. Additional 'grey literature' searches for government guidance and studies' in press were identified using Google and Google Scholar search engines. The citations and abstracts for relevant studies were imported into the Endnote V9.0 bibliographic database and organised into thematic topic folders.

Each study was assessed based on criteria for the relevance and quality of the study in terms of:

- The research provided evidence to answer the research questions
- The paper was written in English (time did not permit translation of other languages)
- Where possible the paper had been accepted after peer review for publication in an established scientific journal
- The methodology used was clearly described and traceable.
- That in addition to their conclusions the authors had identified uncertainties introduced by their methodology or constraints on the research.

Given the urgent requirement for this evidence summary a systematic review was not undertaken. However, the authors adopted a structured approach to searching, sifting and summarising evidence as used in rapid evidence review methodology. Each paper was additionally considered in terms of the adequacy of the methodology and data analysis, and whether the results were likely to be relevant in the context of PPE re-use in the UK and EU. However, some studies were published as short rapid publications and therefore did not provide detailed explanation about methodology or other results obtained.

Topic: PPE re-use + including grey literature

Search log No: 12459

Language Limit?	Year Limit?	Other Limiters?

Language Limit?	Year Limit?	Other Limiters?
No	2000-2020	No

Search Concept 1:
PPE or RPE or “personal protective equipment” or “respiratory protective equipment” or FFP3 or FFP2 or N95 or “filtering facepiece*” or “face mask*” or “face cover*” or “fabric mask*” or “fabric cover*” or “eye protection” or visor* or goggles or “protective gown*” or “disposable gown*” or “disposable mask*” or “reusable apron*” or “disposable apron*” or “disposable oversuit*”

Search Concept 2: AND
Re-use or repurpose or reprocess* or wash* or disinfect* or sterilis* or steriliz* or single use*” or decontaminat* or eradicate* or clean* or treat*

Search Concept 3: OR
(decontamin* or eradicate*) and (virus* or viral)

Database Name:	Number of Results:
Web of Science	16 (first file) + 15 (second file of results)
Embase and Medline (on Proquest platform)	32
Google Scholar / web search for grey literature	10

Topic: PPE re-use

Searchlog No: 12459

Language Limit?	Year Limit?	Other Limiters?
No	2000-2020	No

Search Concept 1:
PPE or RPE or “personal protective equipment” or “respiratory protective equipment” or FFP3 or FFP2 or “filtering facepiece*” or “face mask*” or “face cover*” or “fabric mask*” or “fabric cover*” or “eye protection” or visor* or goggles or “protective gown*” or “disposable gown*” or “disposable mask*” or “reusable apron*” or “disposable apron*” or “disposable oversuit*”

Search Concept 2: AND
Re-use or repurpose or wash* or disinfect* or sterilis* or steriliz* or “single use*” or decontaminat* or eradicate* or clean* or treat*

Search Concept 3: OR
(decontamin* or eradicate*) and (virus* or viral)

Database Name:	Number of Results:
Web of Science Embase Medline	57

Scientific evidence about COVID-19 is vital to inform decision making by HSE and across Government. The national and global scientific evidence base about COVID-19 (SARS-CoV-2) continues to develop. Evidence summaries give the best available evidence on specific questions at the time of their preparation in order to inform the COVID-19 response. Subsequent HSE guidance and advice may therefore have been updated.

This rapid evidence summary considers the reuse of personal protective equipment (PPE) for items designed to be used more than once, and for disposable single use items. Re-use of disposable PPE should only be considered as a last resort during pandemic-related equipment shortages and goes against PPE supply and use legislation. In the event that this last resort is unavoidable, HSE has powers under the COSHH Regulations to approve re-use of single use Respiratory Protective Equipment (RPE). This approval requires robust evidence that effective protection is provided by the specific PPE model following defined decontamination protocols.

HSE scientists prepared this evidence summary to inform decision making by policymakers in UK Government and HSE as well as other experts. NHS England and NHS Improvement (NHSE&I) needed to establish whether PPE can be safely re-used after disinfection to support supplies to health care workers during the pandemic. The review considers evidence available from January 2020 to August 2020. The main question considered is: What is the evidence to support the safe re-use of different types of PPE, including face coverings which are not defined

Published by the Health and Safety Executive 01/2022