

METHOD FOR DECONTAMINATING A GASEOUS MEDIUM CONTAMINATED WITH CONTAMINATING SPECIES IN SUSPENSION

DESCRIPTION

TECHNICAL FIELD

The invention relates to a method for decontaminating a gaseous medium
5 contaminated with contaminating species in suspension.

The gaseous medium may be air and then the method according to the invention is referred to as an atmospheric decontamination method.

The contaminating species or contaminants in suspension may be particularly in the form of solid particles, liquid particles, or else in the form of molecular species.

10 More precisely, the decontamination method according to the invention enables the capture, trapping, drawdown and fixation of these contaminants in suspension, on a solid surface and optionally the decontamination of this surface.

The applications of the method according to the invention are numerous and varied and relate to numerous industrial and household sectors of activity.

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STATE OF THE PRIOR ART

The removal of contaminants, such as fine particles, nanoparticles, dust or fibers, for example asbestos fibers, or indeed toxic molecules in suspension in the atmosphere and, more generally in a gaseous medium, is a problem which arises in numerous fields such as
20 nuclear facility rehabilitation and dismantling worksites or asbestos removal worksites, but also in the purification of air charged with fine particles from heating appliances, particularly wood-burning. This problem can also arise in the case of post-accident scenarios, particularly following a so-called NRBC (Nuclear, Radiological, Biological, Chemical) event or a natural disaster, and/or on sites contaminated with toxic chemical
25 molecules or harmful biological microorganisms present in suspension in the atmosphere.

The removal of these contaminants in suspension involves very complex processing operations, and requires the implementation of specific protocols such as wearing specific equipment (work clothing, breathing protection, etc.), or the set-up of containment airlocks and specific ventilation.

5 Moreover, operators' interventions periods are reduced as they must use restrictive clothing.

Finally, the removal of these contaminants in suspension requires most of the time the shutdown of the worksites in progress.

10 The risks associated with the presence of contaminants in suspension in the atmosphere are essentially risks for the health of workers or the general public but also safety and environmental risks.

The removal of contaminants in suspension greatly impacts the various projects encountering this problem, whether in terms of cost, safety, security, deadlines, or efficiency, etc.

15 The methods for removing contaminants such as (nano)particles, dusts or fibers, for example asbestos fibers, or else toxic molecules in suspension in the atmosphere or, more generally, in a gaseous medium, can be classified into various types, according to the technique used.

A first type of method is that of the methods wherein air filtration is carried out.

20 Thus, the document US-A1-2006/0248866 [1] relates to an air decontamination apparatus for moving filtered air into an enclosed space. This apparatus comprises an enclosure including an air filtration compartment with an inlet and an outlet; at least a first air decontamination filter disposed in the air filtration compartment between the inlet and the outlet, and a device for moving air ("*Air mover*") communicating with the air filtration
25 compartment for moving the air through the air decontamination filter.

According to paragraph [0013], the air decontamination apparatus can comprise a first air decontamination filter selected from the group consisting of a HEPA filter, an active carbon filter, a biological agent filter, a chemical agent filter, and a radioactive agent filter.

30 This device is a conventional device for filtering contaminated air using fixed filters operating under dry conditions and without spraying liquid.

There is no mention or suggestion in this document of spraying a liquid, even less a gel, let alone specifically a vacuumable mineral, inorganic gel, in the specific form of fine droplets in a gaseous medium such as air, with a view to capturing, drawing down, fixing the contaminants, pollutants found in this gaseous medium.

5 The methods of this type, wherein filtration is carried out can also be coupled with photocatalytic methods by incorporating lamps emitting UV rays.

 Thus, the document WO-A3-2004/011041 [2] relates, according to claim 1, to a device for decontaminating air comprising an enclosure defining an air inlet, an air outlet, and a passage for the air to flow from the inlet to the outlet; a fixed filter disposed in the enclosure, along the passage, said filter including an upstream side for receiving the air
10 flowing along the passage, and a downstream side for the outlet of the air from the filter to the passage; at least a first fixed UV lamp disposed so as to directly illuminate the upstream side of the filter; and an ozone generator in the vicinity of the filter.

 This device is a conventional device for filtering contaminated air using a fixed filter
15 operating under dry conditions and without spraying liquid, it also uses a UV lamp, and an ozone generator.

 There is no mention or suggestion in this document of spraying a liquid, and even less a gel, let alone specifically a vacuumable mineral gel, in the specific form of fine droplets in a gaseous medium such as air, with a view to capturing, drawing down, fixing the
20 contaminants, pollutants found in this gaseous medium.

 However, the methods of this type, wherein air filtration is carried out, require the set-up of substantial ventilations to be able to create the air flows required for the filtration.

 The presence of a substantial ventilation can prove, on one hand, difficult to set up
25 on certain worksites and, on the other, inconvenient as the air circulations tend to resuspend contaminants which were not in suspension. Finally, the filters collecting the contaminants represent, after use, non-negligible waste, in terms of volume in particular, and the management thereof can prove to be difficult, in the case of radioactive contamination for example.

A second type of method is that of wet-process methods [3, 4].

The principle of this type of method is to create a mist or a spray, fog of water within the contaminated atmosphere. The droplets of the mist or spray thus take up the aerosols of contaminants in suspension and draw them down to the ground when they fall.

5 Thus, the document EP-A2-1935515 [3] describes a system for decontaminating a facility which includes (Fig. 1 of this document [3]) at least one nozzle (10) permanently installed in the facility (12), a liquid aerosol generator (14) located outside the facility, and means (16) for coupling the external liquid aerosol generator (14) to the nozzle (10). The liquid aerosol generator (14) includes a tank containing a decontamination agent and
10 "propellant means" for expelling the decontamination agent from the tank, via the nozzle (10) in the facility (12). The decontamination agent is preferably sprayed in the facility (12) in the form of a dry mist.

 The dry mist of liquid decontamination agent is allowed to act for a sufficient time for it to achieve the aims thereof, for example cleaning the surfaces of a room if a detergent is
15 used, performing an effective sterilization of the internal surfaces of the room if a disinfectant agent is used, and neutralizing the disinfectant if a neutralizing agent is used.

 There is no mention or suggestion in this document that the liquid decontamination agent which is sprayed is in the form of a gel, let alone specifically a vacuumable mineral gel.

20 The liquid decontamination agent does not contain, in particular, any inorganic viscosifying agent, so that it cannot be in the form of a gel.

 Furthermore, in this document, the aim sought is that of decontaminating the surfaces of a room rather than capturing, drawing down, fixing contaminants, pollutants found in a gaseous medium.

25 The document WO-A1-2010/132949 [4] describes a method for decontaminating a surface or an area contaminated with a contaminant selected from the group consisting of chemical warfare agents, industrial pollutants, pesticides, bioactive proteins, and toxins. This method comprises a step of contacting the contaminated surface or area, space with an aerosol comprising a decontamination agent then, simultaneously, or in succession,

contacting the contaminated surface or area, space with an aerosol comprising an antagonist of the decontamination agent.

5 There is no mention or suggestion in this document that the liquid decontamination agent which is sprayed is in the form of a gel, let alone specifically a vacuumable mineral gel.

The second type of method is currently that most used. Numerous industrial firms thus market various types of spray guns of various geometries for this application. However, this type of method produces effluents which contain the contaminants collected and which can prove to be difficult to process.

10 Post-processing operations for decontaminating effluents must then necessarily be implemented. Furthermore, in the event of drying of the aqueous phase due to natural or forced evaporation, the contaminants drawn down onto the walls can be readily resuspended in the air. In these methods, the contaminants are indeed taken up, captured but the containment thereof is not optimized.

15 A particularly difficult problem to solve is that of the removing asbestos fibers in suspension in the atmosphere on nuclear facility sanitation and dismantling worksites.

Indeed, on asbestos removal worksites, it is necessary to use water, used by misting, spraying, in order to take up, capture the asbestos fibers whereas, on "nuclear" worksites, it is on the contrary preferable to avoid the presence of water to reduce the risks of contamination and to facilitate criticality management.

20 Therefore, in view of the above, there is a need for a method for decontaminating a gaseous medium, such as air, contaminated with contaminating species in suspension which does not involve the drawbacks, defects, limitations and disadvantages of the decontamination methods of the prior art, particularly of the decontamination methods described in the prior art documents cited above. There is also a need for such a method

25 which makes it possible to solve the problems of the methods of the prior art.

The goal of the present invention is that of providing a method for decontaminating a gaseous medium contaminated with contaminating species in suspension which meets inter alia the needs mentioned above.

DESCRIPTION OF THE INVENTION

This goal, and still others, are achieved, according to the invention, by a method for decontaminating a volume of a gaseous medium contaminated with contaminating species in suspension, said volume of a gaseous medium being in contact with at least one surface of a solid substrate, said method comprising the following successive steps:

a) fine droplets are sprayed in said volume of a gaseous medium, thus forming a mist, of an inorganic gel consisting of a colloidal solution comprising an inorganic viscosifying agent and a solvent;

b) the contaminating species in suspension are captured, taken up by said inorganic gel droplets;

c) the inorganic gel droplets containing the captured contaminating species in suspension deposit, settle on said surface of the solid substrate;

d) the gel is kept, maintained on the surface of the solid substrate at least for a sufficient time for the gel to dry and form a dry and solid residue containing the captured contaminating species in suspension;

e) the dry and solid residue containing said captured contaminating species in suspension is recovered.

Advantageously, the gaseous medium is air. It may be atmospheric, ambient air.

Advantageously, the volume of a gaseous medium is an enclosed volume defined by walls ("parois"), such as a floor, a ceiling and walls ("murs"), forming said surface, the mist of fine droplets fills the entire enclosed volume, and the fine droplets of the inorganic gel containing the captured, taken up contaminating species in suspension deposit, settle on at least one of the walls, preferably on all the walls.

Generally, the fine droplets have a size, defined by the greatest dimension thereof, such as a diameter, from 10 to 1000 μm , preferably from 20 to 200 μm .

Generally, the mist is a dense mist.

The man skilled in the art will readily understand what a so-called dense mist is.

The term "gel" is perfectly clear for the man skilled in the art and it has a widely accepted meaning.

However, generally, it can be considered that a gel has a viscosity greater than or equal to 0.1 Pa.s.

5 The gel used according to the invention is described as an inorganic, mineral gel in that it comprises an inorganic, mineral viscosifying agent.

Generally, the gel only contains as viscosifying agent this inorganic, mineral viscosifying agent, and it contains no organic viscosifying agent.

10 The gel used in the method according to the invention may generally be defined in that it is a so-called "vacuumable gel", "suctionable" gel".

The term "vacuumable gel", "suctionable gel" is a term commonly used in this technical field, it has a widely accepted meaning recalled below.

A vacuumable gel is intrinsically different from a gel which is not vacuumable.

Vacuumable gels are historically used specifically for decontaminating surfaces.

15 Note in this regard that, in the context of nuclear decontamination, gelled formulations which make it possible to avoid the problems linked with the powdery nature of the dry waste, and to increase the efficacy of the method using a gel have been the subject of documents [5] and [6].

20 These documents describe inorganic colloidal gels which are therefore so-called "vacuumable gels", namely gels specifically formulated to be sprayed, then to dry while fracturing, while trapping and confining the radioactive contamination in the form of vacuumable and storable flakes.

25 Document [5] describes a gel consisting of a colloidal solution comprising an inorganic thickening agent, generally silica or alumina, an active treatment agent which is for example an inorganic acid or base such as soda or potash, and optionally an oxidizing agent having a normal oxidation-reduction potential E_0 greater than 1.4 V in a strong acidic medium such as Ce(IV), Co(III), or Ag(II).

Document [6] describes a gel consisting of a colloidal solution comprising an organic viscosifying agent, generally silica or alumina, a surfactant, an inorganic acid or base,

optionally an oxidizing agent having a normal oxidation-reduction potential E_0 greater than 1.4 V in a strong acidic medium such as Ce(IV), Co(III), or Ag(II).

These vacuumable inorganic colloidal gels therefore generally comprise an inorganic, mineral viscosifying agent, such as silica or alumina, one or more active decontamination
5 agents, and optionally surfactants and other organic additives.

Due to the different constituents used in the composition thereof, these vacuumable gels have a rheology which enables the spraying thereof on a contaminated surface, then the adhesion thereof to this surface, even vertical, without run-off.

This thus enables prolonged contact between the contaminant and the active
10 decontamination agent, without the mechanical properties of the substrate being altered.

Following the spraying thereof, the gel dries, is fractured, and produces dry residues, called "flakes", adhering to the substrate and which are subsequently removed by brushing or vacuuming for direct packaging.

The decontamination methods which use these vacuumable gels are therefore dry-
15 process surface decontamination methods, not generating any liquid waste and little dry solid residues. Indeed, these dry solid residues only represent on average a quarter of the mass of gel initially sprayed. Furthermore, these methods limit operators' exposure time to radioactive contamination, due to the easy use thereof by spraying followed by vacuuming of the dry residue, and in that the operator's presence is not required while the
20 gel is drying.

The use of these vacuumable, suctionable mineral, inorganic gels in the form of fine droplets forming what is referred to as a mist, spray, fog of gel specifically for decontaminating a gaseous medium contaminated with contaminating species in suspension, and not for decontaminating solid surfaces, has never been described or
25 suggested in the prior art and particularly in documents [5] and [6] cited above.

The method according to the invention comprises a specific succession of specific steps which has never been described or suggested in the prior art as represented and particularly in the documents cited above.

The method according to the invention meets all of the needs and requirements
30 mentioned above, it does not have the drawbacks, defects, limitations and disadvantages

of the methods for decontaminating gaseous media according to the prior art such as those described in the documents mentioned above.

In particular, the method according to the invention makes it possible to provide a satisfactory solution to the problem of removing asbestos fibers in suspension in the atmosphere on nuclear facilities sanitation and dismantling worksites which hitherto
5 seemed to be insurmountable due to the need to meet contradictory requirements.

The method of the present invention is based on the surprising observation that the physicochemical properties of vacuumable gels, which have only been used to date for decontaminating solid surfaces and not gaseous media, render it suitable for being sprayed
10 in the very specific form of fine droplets.

In the methods for decontaminating solid surfaces described above, a homogeneous, cohesive jet of gel is sprayed onto the solid surface.

In the method according to the invention, distinct separate fine droplets, forming a mist, are sprayed, and these droplets are not sprayed onto a solid surface but into a volume
15 of a gaseous medium.

In the methods for decontaminating solid surfaces described above, the gel must be sprayed not far from the surface to be treated, for example at a distance of 30 cm to 1 m, with a strong, high-pressure jet. The travel time, "time of flight" of the jet of gel between the spray nozzle, tip of the device for spraying the gel, and the solid surface is short, for
20 example from one to a few milliseconds, for example 10 milliseconds. It is not sought to increase this time of flight.

In the method for decontaminating a volume of a gaseous medium according to the invention, a solid surface is not treated, but a given volume of a gaseous medium.

Therefore, on the contrary, in the method according to the invention, it is generally
25 sought to give to the fine droplets generated, sprayed, a sufficiently great time of flight in said volume of a gaseous medium, to take up the contaminants in suspension.

In the method according to the invention, the travel time, "time of flight" in the volume of gaseous medium, of the gel droplets from the spray nozzle, tip of the device for spraying the gel, can be considered as being long compared to the "time of flight" of the
30 gel jet in surface contamination methods.

In the method according to the invention, the time of flight of the gel in the volume of gaseous medium may be for example from 100 milliseconds to one or a few seconds, for example, 2, 5, or 9 seconds, or even up to around a ten or some tens of seconds, for example 10, 20, 30, 40, 50, 60 70, 80, 90, or 100 seconds.

5 Preferably, the time of flight of the gel in the volume of gaseous medium may be from 1 to 100 seconds, more preferably from 2 to 50 seconds, better from 3 to 40 seconds, still better from 4 to 30 seconds, particularly from 5 to 20 seconds, particularly from 6 to 10 seconds.

10 A preferred example of such a time of flight is a time of flight of 1 to 10 seconds, for example from 2, 3, 4 or 5 seconds to 10 seconds.

Such a time of flight can be obtained by taking one or more of the following measures:

- the spray nozzle of the spraying device may be placed far (particularly at a distance of several meters, for example, from 2 to 5, 10, or 20 meters) from said at least one surface of a solid substrate, and more generally far (particularly at a distance of several meters, for example from 2 to 5, 10, or 20 meters) from any solid surface whereon the droplets sprayed, formed would be liable to adhere.

20 The ideal consists of forming the gel mist inside, within a large volume of gaseous medium (particularly a volume from 1 m³ to several m³, for example a volume from 1 to 2, 5, 10, or 20 m³).

It should be noted that the filling of the volume will depend on the spraying apparatus.

25 The gel and gas, such as air, pressures sent into the nozzle of the spraying device to form the gel droplets may be set, seeking to reduce the projection, spraying speed (relative to the volume of gaseous medium wherein spraying is carried out) so as to enable the droplets to have a sufficiently great time of flight in the volume of gaseous medium, such as air, to take up, capture the contaminants.

Advantageously, the gel and gas pressures may be each, independently, from 1 to 10 bars, preferably from 1 to 7 bars, more preferably from 1 to 5 bars, better from 1 to 3 bars.

30 For example, the pressures may be from 5 to 10 bars.

The spraying device used to carry out the method according to the invention and the operating parameters thereof are adapted to obtain the extended time of flight mentioned above.

5 It was observed, according to the invention, surprisingly, that thanks to the remarkable rheofluidifying properties thereof, inorganic gels, particularly vacuumable, suctionable gels, which hitherto had only been used for decontaminating solid surfaces, are sprayable in the very specific form of fine droplets.

10 These fine droplets have surprisingly a substantial time of flight enabling them, on the one hand, to remain in suspension in the gaseous medium, such as the atmosphere, for a longer time than during a spraying (in the form of a jet which reaches the surface very quickly) conventionally used for surface contamination operations and, on the other hand, to be capable of filling the entire volume to be decontaminated.

Therefore, it is thanks to this extended time of flight that the gel droplets can come into contact with the contaminating species in suspension in a gaseous medium.

15 The spraying device and method used herein are therefore generally adapted to form a sufficiently dense mist or spray, fog of droplets so that all of the contaminating species present in the volume of gaseous medium to be contaminated are taken up, captured by the gel droplets.

20 The spraying according to the invention of an inorganic gel in the form of a mist or a spray, fog, particularly of a dense mist or spray, fog thus has numerous significant advantages for decontaminating gaseous media, particularly for atmospheric decontamination, inter alia:

- the contaminating species (such as the particles, dusts, asbestos fibers, toxic molecules, etc.) present in suspension are taken up, captured by the gel droplets.
- 25 - the droplets containing the contaminating species deposit, settle onto the solid surface, for example onto the walls ("parois") (such as the floor, walls ("murs"), and ceiling) of the volume to be decontaminated and adhere thereto, fixing in this way the captured, taken up contaminating species.

30 It may be noted that a surface decontamination step may optionally be carried out if a sufficient quantity of gel is sprayed. The droplets then accumulate on the surface of the

solid substrate such as the walls (walls ("murs"), floor, ceiling) of the volume to be decontaminated until a layer of gel is formed thereon, generally of a millimetric thickness and a surface decontamination action is performed.

5 - the gel dries and produces a non-powdery solid waste trapping the contaminating species and preventing the resuspension thereof.

 - the waste containing the contaminating species (which were in suspension, and optionally on the surface and below the surface of the solid substrate) may finally be easily recovered, for example by brushing or vacuuming, suctioning thus not generating any liquid waste for subsequent processing.

10

 The contaminating species in suspension may be in the form of solid particles, liquid particles, or in the form of molecular species.

 The contaminating species may be chemical, biological, nuclear or radioactive contaminating species.

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 The contaminating species which may be removed with the method according to the invention, may be particularly contaminating species that are radioactive, and/or chemically toxic, and/or toxic due to the form, shape, and/or the size thereof.

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 The contaminating species toxic due to the form, shape, and/or the size thereof, may be contaminating species in the form of solid particles such as microparticles, or nanoparticles, for example in the form of fibers such as microfibers or nanofibers, in the form of nanotubes, or in the form of crystals such as nanocrystals.

 These fibers may form a wool, such as a glass wool or a so-called rock wool.

 The toxic contaminating species may particularly be in the form of a dust.

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 It should be noted that some dusts of chemically non-toxic compounds, such as for example cereal or wood dusts, flour, are toxic solely due to the fact that they are specifically in this form of dust.

 The contaminating species may be selected from metals and metalloids in metal, metalloid, or ionic form, preferably from so-called "heavy metals", and toxic metals and metalloids in metal, metalloid, or ionic form; the compounds of these metals and

metalloids such as organometallic compounds, metal salts, metal oxides, metal carbides, etc.; ceramics; wood; cereals; flour; and glasses, for example in the form of glass wool.

According to the invention, the term so-called "heavy metals" denotes all the elements traditionally designated with this term as well as the elements designated with
5 the term metallic trace element, or MTE.

The so-called "heavy metals", and the toxic metals and metalloids are particularly antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, tellurium, thallium and tin.

The contaminating species may be particularly asbestos, in particular asbestos found
10 in a radioactive atmosphere.

The nuclear, radioactive contaminating species may be any chemical compound containing a radionuclide, whether it is in ionic, molecular or particulate form.

The nuclear, radioactive species which may be removed, eliminated by the method according to the invention may be selected for example from metal oxides and hydroxides
15 particularly in the form of solid precipitates.

Advantageously, the colloidal solution further comprises one or several component(s) selected from the following components:

- a surfactant;
- an active decontamination agent;
- 20 – a trapping agent ("getter") to trap the gaseous contaminating species, particularly the toxic or explosive gaseous contaminating species, such as hydrogen;
- a contaminating species extracting agent;
- a contaminating species fixing agent;
- a coloring agent.

25

Preferably, the colloidal solution, comprises, preferably consists of:

- 1% to 30% by mass, preferably 1% to 25% by mass, more preferably 5% to 25% by mass, better 8% to 20% by mass, with respect to the mass of the gel, of at least one inorganic viscosifying agent;

- optionally, 0.1% to 2% by mass with respect to the mass of the gel, of at least one surfactant;
- optionally 0.1 to 10 mol/L of gel, preferably 0.5 to 10 mol/L of gel, more preferably 1 to 10 mol/L of gel, and better from 3 to 6 mol/L of gel, of at least one active decontamination agent;
- optionally, 0.1% to 5% by mass, with respect to the mass of the gel, of at least one trapping agent ("*getter*") to capture, take up, trap the gaseous contaminating species, particularly the toxic or explosive gaseous contaminating species, such as hydrogen;
- optionally, 0.1% to 5% by mass with respect to the mass of the gel, of at least one contaminating species extracting agent;
- optionally, 0.1% to 5% by mass with respect to the mass of the gel, of at least one contaminating species fixing agent;
- optionally, 0.01% to 10% by mass, preferably 0.1% to 5% by mass, with respect to the mass of the gel, of at least one coloring agent;
- and the remainder of solvent.

The sum of the percentages by mass of all the components, constituents of the gel is obviously 100% by mass.

The term "remainder of solvent" denotes that the solvent is always present in the colloidal solution and that the quantity of solvent is a quantity such that, when it is added to the quantities of the components of the colloidal solution other than the solvent (whether these components are mandatory or optional components cited above, or else cited or uncited further optional additional components), the total quantity of all the components of the colloidal solution is 100% by mass.

It should be noted that it is not necessary for the gel to contain one or several of the optional components cited above. Indeed, a gel comprising only the solvent and the viscosifying agent makes it possible to successfully carry out the method according to the invention by trapping, capturing, taking up the contaminating species, and makes it possible to obtain the effects and advantages listed above.

In other words, the colloidal solution, comprises, preferably consists of:

- 1% to 30% by mass, preferably 1% to 25% by mass, more preferably 5% to 25% by mass, better 8% to 20% by mass, with respect to the mass of the gel, of at least one inorganic viscosifying agent; and one or several component(s) selected from the following components, in the following proportions:

5 - 0.1% to 2% by mass with respect to the mass of the gel, of at least one surfactant;

- 0.1 to 10 mol/L of gel, preferably 0.5 to 10 mol/L of gel, more preferably 1 to 10 mol/L of gel, and better from 3 to 6 mol/L of gel, of at least one active decontamination agent;

10 - 0.1% to 5% by mass, with respect to the mass of the gel, of at least one trapping agent ("getter") to trap the gaseous contaminating species, particularly the toxic or explosive gaseous contaminating species, such as hydrogen;

- 0.1% to 5% by mass with respect to the mass of the gel, of at least one contaminating species extracting agent;

15 - 0.1% to 5% by mass with respect to the mass of the gel, of at least one contaminating species fixing agent;

- 0.01% to 10% by mass, preferably 0.1% to 5% by mass, with respect to the mass of the gel, of at least one coloring agent;

- and the remainder of solvent.

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In other words, or else, preferably, the colloidal solution, comprises, preferably consists of:

- 1% to 30% by mass, preferably 1% to 25% by mass, more preferably 5% to 25% by mass, better 8% to 20% by mass, with respect to the mass of the gel, of at least one inorganic viscosifying agent;

25

- and the remainder of solvent.

The presence of a surfactant in the gel used in the method according to the invention has a favorable and notable effect on the rheological properties of the gel. This surfactant particularly promotes the recovery of viscosity of the gel following the spraying,

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nebulization, atomization thereof in the form of fine droplets and prevents the risks of spreading or runoff thereof when the gel is deposited on vertical surfaces and ceilings.

The presence in the gel of at least one active decontamination agent makes it possible to eliminate, destroy, inactivate, kill, extract the contaminating species in suspension and optionally the contaminating species on the surface and under the surface of the solid substrate.

The presence in the gel of at least one contaminating species extracting agent, makes it possible to facilitate the uptake, capture and fixation of the contaminating species present in the gaseous medium and optionally of the contaminating species on the surface.

The presence in the gel of at least one contaminating species fixing agent, such as an organic resin, makes it possible to prevent a release of the contaminating species in the case of a potential leaching of the final dry and solid residue.

The presence of at least one coloring agent in the gel makes it possible to better visualize, identify the final dry and solid residue at the end of the method, regardless of the surface whereon it is deposited, which facilitates the recovery of this residue.

The gel used according to the invention is a colloidal solution, which means that the gel according to the invention contains inorganic, mineral solid particles of viscosifying agent wherein the elementary, primary particles have a size generally of 2 to 200 nm.

Due to the use of a generally exclusively inorganic viscosifying agent, without any organic viscosifying agent, the organic matter content of the gel used according to the invention is generally less than 4% by mass, preferably less than 2% by mass, which represents an advantage of the gels used according to the invention.

These mineral, inorganic solid particles act as a viscosifying agent to enable the solution, for example the aqueous solution, to gel.

Advantageously, the inorganic viscosifying agent may be selected from metal oxides such as aluminas, metalloid oxides such as silicas, metal hydroxides, metalloid hydroxides, metal oxyhydroxides, metalloid oxyhydroxides, aluminosilicates, clays such as smectite, and mixtures thereof.

In particular, the inorganic viscosifying agent may be selected from aluminas (Al_2O_3) and silicas (SiO_2).

The inorganic viscosifying agent may only comprise one single silica or alumina or a mixture thereof, namely a mixture of two different silicas or more ($\text{SiO}_2/\text{SiO}_2$ mixture), a mixture of two different aluminas, or more ($\text{Al}_2\text{O}_3/\text{Al}_2\text{O}_3$ mixture), or indeed a mixture of one or more silicas with one or more aluminas ($\text{SiO}_2/\text{Al}_2\text{O}_3$ mixture).

5 Advantageously, the inorganic viscosifying agent may be selected from pyrogenic silicas, precipitated silicas, hydrophilic silicas, hydrophobic silicas, acidic silicas, basic silicas such as Tixosil® 73 silica, marketed by the Rhodia Company, and mixtures thereof.

 Among the acidic silicas, mention may particularly be made of the pyrogenic or fumed silicas "Cab-O-Sil"® M5, H5 or EH5 silica, marketed by the CABOT® Company, and of the
10 pyrogenic silicas marketed by the EVONIK INDUSTRIES® Company under the trade name AEROSIL®.

 Among these pyrogenic silicas, AEROSIL® 380 silica of a specific surface area of 380 m^2/g which offers maximum viscosifying properties for a minimum mineral load is preferred.

15 The silica used may also be a so-called precipitated silica obtained for example by a wet process by mixing a solution of sodium silicate and an acid. The preferred precipitated silicas are marketed by the EVONIK INDUSTRIES® Company under the name SIPERNAT® 22 LS and FK 310 or else by the RHODIA® Company under the name TIXOSIL® 331, the latter is a precipitated silica wherein the mean specific surface area is between 170 and 200 m^2/g .

20 Advantageously, the inorganic viscosifying agent consists of a mixture of a precipitated silica and a pyrogenic silica.

 The alumina may be selected from calcined aluminas, ground calcined aluminas, and mixtures thereof.

 Advantageously, the inorganic viscosifying agent may consist of one or several
25 alumina(s) generally representing from 5% to 30% by mass with respect to the total mass of the gel.

 In this case, the alumina(s) is (are) preferably at a concentration of 8% to 17% by mass with respect to the total mass of the gel to ensure drying of the gel at a temperature between 20°C and 50°C and at a relative humidity between 20% and 60% on average in 30
30 minutes to 5 hours.

Advantageously, the alumina(s) may be selected from pyrogenic aluminas, preferably from fine-grained pyrogenic aluminas.

By way of example, mention may be made of the product sold by the EVONIK INDUSTRIES® Company under the trade name "Aeroxide Alu C" which is a pyrogenic fine alumina.

The nature of the mineral viscosifying agent, particularly when it consists of one or more alumina(s), unexpectedly influences the drying of the gel used according to the invention and the particle size of the residue obtained.

Indeed, the dry gel is in the form of particles of controlled size, more specifically of millimetric solid flakes, the size whereof ranges generally from 1 to 10 mm, preferably from 2 to 5 mm thanks particularly to the compositions cited above, in particular when the viscosifying agent consists of one or more alumina(s).

Note that the particles size generally corresponds to the greatest dimension of said particles.

In other words, the mineral solid particles of the gel used according to the invention, for example of silica or alumina type, besides the role of viscosifying agent thereof, also play a fundamental role during the drying of the gel as they ensure the fracturation of the gel to obtain a dry waste in the form of flakes.

The gel used according to the invention may contain an active decontamination agent.

This active decontamination agent may be any active decontamination agent suitable for removing a contaminating species regardless of the nature of this contaminating species: whether this contaminating species is chemical, biological or nuclear, radioactive — in other words, this decontamination agent may be any "NRBC" (Nuclear, Biological, Radiological, Chemical) decontamination agent — or this contaminating species is organic or mineral, liquid or solid.

The gel used according to the invention may contain a biological or chemical or nuclear, radioactive active decontamination agent.

The active decontamination agent may also be a degreasing, stripping agent so as to remove a contaminating species found on the surface and optionally under the surface, in the depth of the substrate.

5 Some active decontamination agents may simultaneously fulfil several decontamination functions.

The term biological decontamination agent that may also be described as a biocidal agent denotes any agent, which when it is placed in contact with a biological species and particularly a toxic biological species is capable of inactivating or destroying it.

10 The term biological species denotes any type of microorganism such as bacteria, fungi, yeasts, viruses, toxins, spores particularly *Bacillus anthracis* spores, prions, and protozoa.

The biological species which are removed, eliminated, destroyed, inactivated, by the gel used according to the invention are essentially biotoxic species such as pathogenic spores such as for example *Bacillus anthracis* spores, toxins such as for example botulinic toxin or ricin, bacteria such as *Yersinia pestis* bacteria and viruses such as the vaccinia virus or hemorrhagic fever viruses for example of Ebola type.

15 The term chemical decontamination agent denotes any agent, which when it is placed in contact with a chemical species and especially a toxic chemical species is capable of destroying or inactivating it.

20 The chemical species which are removed, eliminated by the gel used in the method according to the invention are particularly toxic chemical species such as toxic, in particular neurotoxic or vesicant, gases.

25 These toxic gases are particularly organophosphorus compounds, of which mention may be made of Sarin or agent GB, VX, Tabun or agent GA, Soman, Cyclosarin, diisopropyl fluoro phosphonate (DFP), Amiton or agent VG, Parathion. Further toxic gases are mustard gas or agent H or agent HD, Lewisite or agent L, agent T.

30 The active decontamination agent, for example the active biological or chemical decontamination agent may be selected from bases such as sodium hydroxide, potassium hydroxide, and mixtures thereof; acids such as nitric acid, phosphoric acid, hydrochloric acid, sulfuric acid, hydrogen oxalates such as sodium hydrogen oxalate, and mixtures

thereof; oxidizing agents such as peroxides, permanganates, persulfates, ozone, hypochlorites such as sodium hypochlorite, cerium IV salts, and mixtures thereof; quaternary ammonium salts such as hexadecylpyridinium (cetylpyridinium) salts, such as hexadecylpyridinium (cetylpyridinium) chloride; reducing agents; and mixtures thereof.

5 For example, the active decontamination agent may be a disinfectant agent such as bleach ("Eau de Javel"), which gives the gel biological and/or chemical decontamination, depollution properties.

 Some active decontamination agents may be classified among several of the categories defined above.

10 Thus, nitric acid is an acid, but also an oxidizing agent.

 The active decontamination agent, such as a biocidal agent, is generally used at a concentration from 0.1 to 10 mol/L of gel, preferably from 0.5 to 10 mol/L of gel, more preferably from 1 to 10 mol/L, and better from 3 to 6 mol/L of gel in order to guarantee a decontamination potential, power for example an inhibition potential, power of the
15 biological, particularly biotoxic, species, compatible with the gel drying time, and to ensure for example drying of the gel at a temperature between 20°C and 50°C and at a relative humidity between 20% and 60% on average in 30 minutes to 5 hours.

 So as to achieve complete efficacy, including under the least favorable temperature and humidity conditions with respect to the drying time, the formulation of the gel accepts
20 different active agent concentrations. It may be noted, indeed, that increasing the concentration of the decontamination agent, more specifically of the acidic or basic decontamination agent increases the drying time of the gel and therefore the efficacy of the method considerably.

 The active decontamination agent may be an acid or a mixture of acids. These acids
25 are generally selected from mineral acids such as hydrochloric acid, nitric acid, sulfuric acid and phosphoric acid.

 A decontamination agent, particularly a biological decontaminating agent that is particularly preferred is nitric acid.

 Indeed, it was found entirely surprisingly that nitric acid destroyed, inactivated
30 biological, particularly biotoxic, species.

In particular, it was demonstrated surprisingly that nitric acid destroyed, inactivated spores such as *Bacillus thuringiensis* spores which are particularly resistant species.

The acid or acids is (are) preferably present at a concentration from 0.5 to 10 mol/L, more preferably from 1 to 10 mol/L, better from 3 to 6 mol/L to ensure drying of the gel
5 generally at a temperature between 20°C and 50°C and at a relative humidity between 20% and 60% on average in 30 minutes to 5 hours.

For this type of acid gel, the inorganic viscosifying agent is preferably silica or a mixture of silicas.

Or else, the active decontamination agent for example the biological active
10 decontamination agent may be a base, preferably a mineral base, selected preferably from soda, potash, and mixtures thereof.

In the case of such a basic gel formulation, the gel according to the invention has, besides the decontamination action, a degreasing action which makes it possible to also remove, eliminate any contaminating species on the surface of the substrate.

15 As already mentioned above, so as to achieve complete efficacy, including under the least favorable climatic conditions with respect to the gel drying time, the gel according to the invention may have a wide concentration range of basic decontamination agent(s).

Indeed, increasing the concentration of basic decontamination agent such as NaOH or KOH, generally acting as a biocidal agent, makes it possible to increase the inhibition
20 rates of the biological species considerably, as demonstrated for *Bacillus thuringiensis* spores.

The base is advantageously present at a concentration of less than 10 mol/L, preferably between 0.5 and 7 mol/L, more preferably between 1 and 5 mol/L, better between 3 and 6 mol/L, to ensure drying of the gel at a temperature between 20°C and
25 50°C and at a relative humidity between 20% and 60% on average in 30 minutes to 5 hours.

For this type of alkaline, basic, gel, the inorganic viscosifying agent is preferably an alumina or a mixture of aluminas.

The decontamination agent, in particular when it is a biological decontamination agent is preferably sodium hydroxide or potassium hydroxide.

In view for example of the spores inhibition kinetics and of the gel drying times according to the temperature, the active decontamination agent, particularly when it is a biocidal agent will be preferably sodium hydroxide at a concentration between 1 and 5 mol/L.

5 The gel may optionally also contain a surfactant or a mixture of surfactants, preferably selected from the family of non-ionic surfactants such as block, sequenced copolymers such as ethylene oxide and propylene oxide block copolymers, and ethoxylated fatty acids; and mixtures thereof.

10 For this type of gel, the surfactants are preferably block copolymers marketed by the BASF® Company under the trade name PLURONIC®.

Pluronic® are sequenced copolymers of ethylene oxide and propylene oxide.

These surfactants influence the rheological properties of the gel, particularly the thixotropic nature of the product and the recovery time and prevent the occurrence of runoff.

15 Surfactants make it possible, moreover, to control the adhesion of the dry waste, and control the size of the flakes of dry residue to ensure that the waste is non-powdery.

Advantageously, the trapping agent ("*getter*") is selected from very high specific surface area solids which contain active surface sites, such as porous carbons, for example active carbons; cage materials particles, such as zeolite and MOF particles; and mineral
20 oxide particles capable of reacting with the contaminating species to be trapped and more specifically with hydrogen, such as manganese oxides (MnO_3 , Mn_2O_3 , Mn_2O_4) and noble metal oxides, for example Ag_2O or RuO_2 .

Advantageously, the contaminating species fixing agent is selected from organic resins, such as polyurethane resins, epoxy resins, acrylic resins, etc.

25 Advantageously, the contaminating species extracting agent is selected from inorganic adsorbents such as zeolites, clays, phosphates such as apatites, titanates such as sodium titanates, and ferrocyanides and ferricyanides.

This optional extracting agent such as a zeolite or a clay may be used if the contaminating species is a radionuclide, but this optional extracting agent may also be used

in the case of contaminating species other than radionuclides, such as for example metals, such as toxic metals or heavy metals.

Advantageously, the coloring agent is selected from dyes, preferably organic dyes, and pigments, preferably mineral dyes.

5 Advantageously, the pigment is a mineral pigment. In this respect, reference may be made to the document WO-A1-2014/154817 [7].

There is no restriction as to the mineral pigment which is incorporated in the gel used according to the invention.

10 Generally, the mineral pigment is selected from the mineral pigments which are stable in the gel.

The term stable pigment generally denotes that the pigment does not exhibit any stable changes of the color thereof over time, when storing the gel for a minimum period of 6 months.

15 There is no limitation as to the color of this pigment, which is generally the color that it will impart to the gel. This pigment can be black, red, blue, green, yellow, orange, purple, brown, etc., and even white in color.

Generally, the gel therefore has a color which is identical to the color of the pigment contained therein. It is however possible for the gel to have a color that differs from the color of the pigment contained therein but this is not sought.

20 The pigment, particularly when it is white, is generally different from the inorganic viscosifying agent.

Advantageously, the mineral pigment is selected such that it gives the gel after drying a color different from the color of the surface whereon the gel is deposited.

25 Advantageously, the mineral pigment is a micronized pigment, and the mean particle size of the mineral pigment may be from 0.05 to 5 μm , preferably from 0.1 to 1 μm .

The fact that the pigment is micronized helps prevent it from modifying the rheology and the spraying capability of the gel ("sprayability") as the pigment then has the same micrometric size which is generally that of the inorganic viscosifying agent, such as alumina aggregates.

Advantageously, the mineral pigment is selected from metal(s) and/or metalloid(s) oxides, metal(s) and/or metalloid(s) hydroxides, metal(s) and/or metalloid(s) oxyhydroxides, metal(s) ferrocyanides and ferricyanides, metal aluminate(s), and mixtures thereof.

5 Preferably, the mineral pigment is selected from iron oxides, preferably micronized, and mixtures thereof.

The iron oxides may have different colors, they may for example be yellow, red, purple, orange, brown, or black.

10 Indeed, iron oxide pigments are recognized as having a good covering power and a high resistance to acids and bases.

For incorporation in a decontamination gel, iron oxides have the best performances in terms of stability and coloring power. Thus, an iron oxide content of 0.1%, or even 0.01% by mass is sufficient to strongly color the gel without modifying the properties thereof.

15 As already mentioned above, the fact that the iron oxide pigment is preferably micronized helps prevent it from modifying the rheology and the spraying capability of the gel ("sprayability") as the pigment then has a micrometric size, namely a size which is generally that of the inorganic viscosifying agent, such as alumina aggregates.

Micronized iron oxides are available from the Rockwood® Company under the trade name Ferroxiide®.

20 Mention may be made, inter alia, of Ferroxiide® 212 M which is a micronized red iron oxide with a mean particle size of 0.1 µm and Ferroxiide® 228 M which is a micronized red iron oxide with a mean particle size of 0.5 µm.

25 In addition to and/or instead of iron oxides, other colored metal or metalloid oxides or hydroxides may be incorporated in the gel according to the invention, according to the pH of the gel, mention may particularly be made of vanadium oxide (V₂O₅) which is orange, manganese oxide (MnO₂) which is black, cobalt oxide which is blue or green, and rare earth oxides. However, iron oxides are preferred for the reasons specified above.

Among the oxyhydroxides, mention may be made of goethite, i.e. iron oxyhydroxide FeOOH, which is highly colored.

By way of example of a metal ferrocyanide, mention may be made of Prussian blue, i.e., ferric ferrocyanide, and by way of example of an aluminate, mention may be made of cobalt blue, i.e., cobalt aluminate.

5 The solvent of the gel used according to the invention is generally selected from water, organic solvents, and mixtures thereof.

A preferred solvent is water, and in this case, the solvent therefore consists of water, comprises 100% water.

10 In the case where the surface of the solid substrate, for example the walls of the enclosed volume, is contaminated with at least one contaminating species referred to as a surface contaminating species located on said surface and optionally under said surface, in the depth of the substrate, the gel then contains a decontamination agent as described above, and during step d) the gel is kept on the surface at least for a sufficient time for the gel to destroy and/or inactivate and/or absorb the surface contaminating species, and for the gel to dry and form a dry and solid residue containing said surface contaminating species and the contaminating species in suspension taken up, captured by the gel.

15 In this embodiment, the method according to the invention makes it possible, in a first phase, to carry out the decontamination of a gaseous medium, for example an atmospheric decontamination then, in a second phase, to carry out a surface decontamination of the solid substrate.

20 The surface contaminated species may be in solid, massive or particulate form, contained in a surface layer of the material of the substrate, in the form of a film or contained in a film, for example a film of greases on the surface of the substrate, in the form of a layer or contained in a layer, for example a layer of paint on the surface of the substrate, or simply deposited on the surface of the substrate.

25 According to the nature of the contamination, the modes of action of the gels differ: erosion of the support material containing the contamination, solubilization of the contaminating film, for example of greases, or of the coating film for example of paint, or else in-situ inactivation of the chemical or biological contaminants in the case of pathogenic species (anthrax).

As already mentioned above, in the case of a basic gel formulation (the decontamination agent is a base), the gel according to the invention has, besides the decontamination action, a degreasing action.

5 When the decontamination agent is an acid or a base, the gel may carry out a decontamination of the surface of the substrate by corroding over a few microns this surface whereon it is deposited.

It should be noted that in the case of radioactive species, it is not a question of destruction or inactivation but merely of removal, elimination of the contamination by dissolving the irradiating deposits or by corrosion of the materials support of the contamination. Therefore, there is actually a transfer of the nuclear contamination to the dry gel flakes.

It should be noted that, in the case of a non-porous surface, the contamination, for example the "inactivated" biological contamination, is recovered by the dry gel flakes.

15 On the other hand, in the case of deep contamination, as in the case of porous materials such as cement matrixes, the dry gel will only contain the surface contamination residue.

However, the efficacy of the method according to the invention is equally good in the presence of a non-porous and/or non-mineral surface.

Advantageously, the solid substrate is made of at least one solid material selected from metals and metal alloys such as stainless steel, painted steels, aluminum, and lead; polymers such as plastics or rubbers such as polyvinyl chlorides or PVCs, polypropylenes or PPs, polyethylenes or PEs particularly high-density polyethylenes or HDPEs, polymethyl methacrylates or PMMAs, polyvinylidene fluorides or PVDFs, polycarbonates or PCs; glass; cements and cement materials; mortars and concretes; plasters; bricks; natural or artificial stone; ceramics.

The surface contaminating species may be selected from the chemical, biological, nuclear or radioactive species already listed above as regards the contaminating species in suspension, and particularly from the toxic biological species already listed above.

Advantageously, it is then ensured that the quantity of gel deposited on the surface to be decontaminated is sufficient to carry out said decontamination on the surface and optionally under the surface of the substrate.

Advantageously, the amount of gel deposited may be from 100 g to 2000 g of gel per m² of surface, preferably from 500 to 1500 g of gel per m² of surface, more preferably from 600 to 1000 g of gel per m² of surface, which generally corresponds to a thickness of gel deposited on the surface between 0.5 mm and 2 mm.

Advantageously, during step d), the drying is carried out at a temperature from 1°C to 50°C, preferably from 15°C to 25°C, and at a relative humidity from 20% to 80%, preferably from 20% to 70%.

Advantageously, the gel is kept on the surface for a time from 2 to 72 hours, preferably from 2 to 48 hours, more preferably from 3 to 24 hours.

Advantageously, the dry and solid residue is in the form of particles, for example flakes, of a size from 1 to 10 mm, preferably from 2 to 5 mm.

Advantageously, the dry and solid residue is removed from the solid surface by brushing and/or vacuuming, suctioning.

When a surface decontamination is carried out, the method according to the invention has all the known advantageous properties inherent in the decontamination gel used in the method, for example:

- adherence to the walls,
- obtaining maximum decontamination efficacy at the end of the gel drying phase,

In general, it is ensured that the drying time is greater than or equal to the time required for inactivation.

- treatment of a very wide range of materials,
- absence of mechanical or physical alteration of the materials following the treatment,
- use of the method under variable climatic conditions,
- reduction of the waste volume,
- ease of recovery of the dry waste.

Further features and advantages of the invention will emerge more clearly on reading the following detailed description, this description being made by way of illustration and not limitation, in conjunction with the attached drawings.

5

BRIEF DESCRIPTION OF THE DRAWINGS

- Figure 1 is a schematic vertical sectional view of a device, used in the method according to the invention, for spraying fine droplets of a gel.
- Figure 2 is a graph which shows the variations in viscosity (in Pa.s) as a function of shear rate (1/s), for the gel referred to as "Gel-1" prepared in example 1 (see example 2).
- Figure 3 is a graph which shows the variations in viscosity (in Pa.s) as a function of time (in sec.), for the gel referred to as "Gel-1" prepared in example 1 (see example 2).
- Figure 4 is a graph which shows the variations in shear stress (in Pa) as a function of deformation (in Pa), for the gel referred to as "Gel-1" prepared in example 1 (see example 2).
- Figure 5 is a photograph taken with a Scanning Electron Microscope (SEM) of the dried gel droplets obtained after spraying and drying the gel referred to as "Gel-1" prepared in example 1. The droplets sprayed from the nozzle are recovered on an adhesive carbon patch deposited in a corner of the volume wherein the mist was sprayed (see example 3).
- Figure 6 is a photograph showing the filling of an enclosed volume of 4.5 m³ with a mist of the gel referred to as "Gel-1" prepared in example 1 (see example 4).

25

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

The gel used in the method according to the invention can be easily prepared at ambient temperature.

For example, the gel according to the invention can be prepared by preferably gradually adding, the inorganic viscosifying agent(s), for example the alumina(s) and/or the

silica(s), to the solvent such as water, preferably deionized water, or to a mixture of the solvent and of one or several component(s) selected from the components already listed above, namely: a surfactant; an active decontamination agent; a trapping agent ("*getter*"); a contaminant fixing agent; a coloring agent.

5 This mixture can be produced by mechanical stirring, for example by means of a mechanical stirrer equipped with a three-blade impeller. The rotational speed is for example 200 rpm, and the stirring time is for example from 3 to 5 minutes.

 The addition of the inorganic viscosifying agent(s) to the solvent or to the mixture of the solvent and of the component(s) cited above may be carried out by simply pouring the
10 viscosifying agent(s) into said mixture. When adding the inorganic viscosifying agent(s), the mixture containing the solvent, this or these inorganic viscosifying agent(s), and optionally the component(s) cited above is generally kept under mechanical stirring.

 This stirring can be, for example, carried out by means of a mechanical stirrer equipped with a three-blade impeller.

15 The stirring speed is generally gradually increased as the viscosity of the solution increases, to ultimately reach a stirring speed for example of between 400 and 600 rpm when all of the inorganic viscosifying agent(s) has been added, without any splashes.

 After the end of the addition of the inorganic (mineral) viscosifying agent(s), the stirring is maintained, for example for 2 to 5 minutes, so as to obtain a perfectly
20 homogeneous gel.

 The gel prepared is then allowed to rest for at least one hour before use.

 It is obvious that further protocols for preparing the gels used in the method according to the invention can be used with an addition of the components of the gel in a different order from that mentioned above.

25 Generally, the gel according to the invention must have a viscosity less than 200 mPa.s at a shear of 1000s^{-1} so that it can be sprayed, nebulized, atomized, in the form of fine droplets as defined above.

 The viscosity recovery time must generally be less than or equal to one second and the low-shear viscosity greater than 10 Pa.s so as not to run on a wall.

The gel prepared as described above is then sprayed, nebulized in a gaseous medium in the form of fine droplets.

These fine droplets form a mist or a spray, fog which generally fill the entire volume of gaseous medium to be decontaminated.

5 Thus in the case where the gaseous medium is located in an enclosed volume defined by walls (“parois”), such as a floor, ceiling and walls (“murs”), the droplets mist fills the entire enclosed volume.

10 This mist or this spray, fog is generally sufficiently dense for all of the contaminating species in suspension in the volume of gaseous medium to be taken up, captured by the gel droplets.

The gel may be sprayed by any device suitable for spraying the gel in the form of fine droplets forming a spray, fog, or mist, preferably a spray, fog, or mist having a sufficient density to take up, capture all of the contaminating species in suspension in the volume of gaseous medium to be decontaminated.

15 Furthermore, as already explained above, the spraying device used to carry out the method according to the invention, and the operating parameters thereof are adapted to obtain the extended time of flight mentioned above.

Figure 1 represents an example of such a spraying device.

20 This device comprises a tank or casing (1) which contains the gel (2), a fluid regulator (3) for setting the fluid pressure P_{fluid} (i.e., the pressure applied in the tank or casing (1)) and an air regulator (4) for setting the air pressure P_{air} , a spray gun (5) equipped with a spray nozzle (6), and an actuator (7). This device only operates with compressed air (for example at a pressure of 5 to 10 bar) (8), conveyed via a pipe (9), no electrical power supply or other power source is required. The casing or tank (1) is first of all filled with
25 gel (2). The casing or tank (1) is then pressurized (1 to 7 bar) using the fluid regulator (3) to enable the gel to reach the spray gun (5) and the spray nozzle (6) via the pipe (10).

30 A gel mist (11) is created by applying a fluid pressure at the spray nozzle (6), for example a pressure of 1 to 10 bar, preferably of 1 to 7 bar, more preferably of 1 to 5 bar, better of 1 to 3 bar, and an air pressure, for example a pressure of 1 to 10 bar, preferably of 1 to 7 bar, more preferably of 1 to 5 bar, better of 1 to 3 bar.

The gel droplets forming a mist, spray, fog or nebulized gel are sprayed into a volume of a gaseous medium containing the contaminating species in suspension.

It may be said that the contaminating species may be in the form of a solid or liquid aerosol, i.e., in the form of a set of solid or liquid, fine particles in suspension in the gaseous medium.

In other words, the contaminating species may be in the form of a particulate suspension (of nanoparticles, dusts, fibers for example asbestos fibers) in a gaseous medium.

The contaminating species may also be in the form of a suspension of molecular species, for example chemical or biological, within a gaseous medium.

The volume of gaseous medium is in contact with at least one surface of a solid substrate, this surface can be for example the surface of the floor.

The volume can be an open volume, for example an outside volume, only delimited by a single surface such as the surface of the floor.

Or else the volume may be an enclosed volume defined by walls ("parois"), such as a floor, ceiling and walls ("murs"). The mist of droplets then fills the entire enclosed volume and the droplets of the inorganic gel containing the captured contaminating species in suspension deposit, settle on at least one of these walls, preferably on all the walls.

Apart possibly from alloys of light metals such as aluminum, if basic or acidic gels are used, there is no limitation as to the material constituting the surface of the substrate. Indeed, the gel used according to the invention makes it possible to treat all kinds of materials, even fragile, without any damage.

This solid substrate material may therefore be selected from for example metals and alloys such as stainless steel, aluminum, and lead; polymers such as plastics or rubbers of which mention may be made of PVCs, PPs, PEs particularly HDPEs, PMMAs, PVDFs, PCs; glasses; cements and cement materials; mortars and concretes; plasters; bricks; natural or artificial stone; ceramics.

In any case, regardless of the material, if according to the invention a surface decontamination is carried out, the decontamination efficacy with the gel is complete.

The surface of the substrate may be painted or unpainted.

If, according to the invention, a surface decontamination is carried out, the efficacy of the treatment with the gel used according to the invention is generally complete.

There is also no limitation as to the shape, geometry and size of the surface of the substrate, which may be a surface to be decontaminated, the method according to the invention enables the treatment of surfaces of large sizes, complex geometries, having for
5 example hollows, corners, edges, recesses.

The method according to the invention, if according to the invention a surface decontamination is carried out, ensures the effective treatment not only of horizontal surfaces such as floors, but also of vertical surfaces such as walls ("murs"), or inclined or
10 overhanging surfaces such as ceilings.

Compared to existing decontamination methods, for example biological decontamination methods using liquids such as solutions, the decontamination method according to the invention — if according to the invention a surface decontamination is carried out — using a gel is particularly advantageous for treating materials of large surface
15 area, that are not transportable and installed outside. Indeed, the method according to the invention due to the use of a gel, enables the in-situ decontamination by preventing the dispersal of chemical solutions in the environment and the dispersion of contaminating species.

The sufficiently short viscosity recovery time of the gels used according to the invention enables the sprayed gels to adhere to all surfaces, for example to walls.
20

The quantity of gel deposited on the surface is generally from 100 to 2000 g/m², preferably from 500 to 1500 g/m², more preferably from 600 to 1000 g/m².

The quantity of gel deposited per unit of surface area and, consequently, the thickness of the gel deposited influences the drying rate.

Thus, when a film, layer of gel of a thickness of 0.5 mm to 2 mm is deposited on the surface to be treated, the effective contact time between the gel and the materials is then
25 equivalent to the drying time thereof, the period during which the active substance contained in the gel will interact with the possible surface contamination.

Furthermore, it was demonstrated surprisingly that the quantity of gel deposited
30 when it is within the ranges mentioned above and in particular when it is greater than or

equal to 500 g/m^2 and particularly within the range from 500 to 1500 g/m^2 , which corresponds to a minimum deposited gel thickness, for example greater than or equal to $500 \mu\text{m}$ for a quantity of gel deposited greater than or equal to 500 g/m^2 , made it possible after drying the gel to obtain a fracturing of the gel in the form of millimetric vacuumable, suctionable flakes, for example of a size of 1 to 10 mm, preferably from 2 to 5 mm.

A deposited gel thickness of $500 \mu\text{m}$ can be easily achieved if gel droplets are sprayed for a sufficient length of time or in a sufficient quantity.

The quantity of gel deposited and therefore the deposited gel thickness, preferably greater than 500 g/m^2 i.e. $500 \mu\text{m}$, is the fundamental parameter influencing the size of the dry residues formed after drying the gel and which thus ensures that dry residues of millimetric size and not powdery residues are formed, such residues being easily removed by a mechanical method and, preferably, by vacuuming.

However, it should also be noted that thanks to the optional surfactant at a low concentration, generally from 0.1% to 2% of the total mass of the gel, the drying of the gel is enhanced and results in a homogeneous fracturing phenomenon with a mono-dispersed dry residue size and an increased ability of the dry residue to become detached from the support.

The gel is then kept on the surface to be treated for the entire time required for the drying thereof. During this drying step, the solvent contained in the gel, namely generally the water contained in the gel is evaporated until a dry and solid residue is obtained.

The drying time is dependent on the composition of the gel within the concentration ranges of the constituents thereof given above, but also, as already specified, on the quantity of gel deposited per unit of surface area, i.e., on the deposited gel thickness.

The drying time is also dependent on the climatic conditions, namely the temperature and the relative humidity of the atmosphere wherein the solid surface is located.

The method according to the invention can be used under extremely broad climatic conditions, namely at a temperature T from 1°C to 50°C and at a relative humidity RH from 20% to 80%.

The drying time of the gel according to the invention is therefore generally from 1 hour to 24 hours at a temperature T from 1°C to 50°C and at a relative humidity RH from 20% to 80%.

It should be noted that the formulation of the gel used according to the invention, particularly when surfactants such as "Pluronic[®]" generally ensure a drying time which is substantially equivalent to the contact time (between the decontamination agent, such as a biocidal agent, and the possible surface contaminating species, for example the biological species, particularly the biotoxic species to be removed, eliminated) which is necessary, required to inactivate and/or absorb the possible surface contaminating species polluting the material of the substrate, and/or to sufficiently achieve the surface erosion reactions of the material of the substrate.

In other words, the formulation of the gel ensures a drying time which is none other than the inactivation time of the surface contaminating species, for example of the biological species, which is compatible with the inhibition kinetics of the contamination, for example of the surface biological contamination

Or else, the formulation of the gel ensures a drying time which is none other than the time required for the erosion reactions making it possible to optionally remove a contaminated surface layer of the material.

In the case of radioactive surface contaminating species, the contamination is removed, eliminated, by dissolving the irradiating deposits or by corroding the materials support of the contamination. Therefore, there is actually a transfer of the nuclear contamination to the dry gel flakes.

The specific surface area of the mineral load generally used which is generally from 50 m²/g to 300 m²/g, preferably 100 m²/g and the absorption capacity of the gel according to the invention make it possible to trap the surface contamination

Where applicable, the contaminating species, for example the biological contaminating species are inactivated in the gelled phase. After drying the gel, the contamination, for example the inactivated biological contamination is removed when recovering the dry gel residue described below.

At the end of the drying of the gel, the gel is fractured homogeneously to give millimetric solid dry residues, for example from 1 to 10 mm in size, preferably from 2 to 5 mm in non-powdery form, generally in the form of solid flakes. The dry residues may contain the contaminating specie(s) in suspension and the inactivated surface
5 contaminating specie(s).

The dry residues, such as flakes, obtained at the end of the drying have a poor adherence to the surface (2) of the material of the substrate. For this reason, the dry residue obtained after drying the gel may be easily recovered by merely brushing and/or vacuuming. However, the dry residue may also be removed with a gas jet, for example with
10 a compressed air jet.

Thus, no rinsing with a liquid is generally required, and the method according to the invention generates no secondary effluent.

However, it is possible, though not preferred, if one so wishes, to remove the dry residues by means of a liquid jet.

15 The method according to the invention therefore thus firstly makes significant savings of chemical reagents compared to a decontamination method by scrubbing with a solution. Then, because a waste in the form of a directly vacuumable dry residue is obtained, a rinsing operation with water or with a liquid, generally required to remove the traces of chemical agents from the part, is generally avoided. This obviously results in a
20 decrease in the quantity of effluents produced but also in a substantial simplification in terms of waste treatment process and outlet.

At the end of the method according to the invention, solid waste is recovered in the form of flakes suitable for being packaged as is, directly packable, this results as already stated above, in a significant decrease in the quantity of effluents produced as well as in a
25 substantial simplification in terms of waste treatment process and outlet.

Furthermore, in the nuclear field, not having to reprocess the flakes before packaging the waste represents a considerable advantage; this allows the use of high-performance active agents hitherto prohibited in decontamination liquids due to liquid effluent treatment plant ("LETP") operating constraints.

The gel may therefore contain strong oxidizing agents such as cerium IV which can easily be regenerated from electrolysis of cerium III.

By way of example, in the current case where 1000 grams of gel is deposited per m² of surface area treated, the mass of dry waste produced is less than 200 grams per m².

5 The invention will now be described with reference to the following examples, given by way of illustration and not limitation.

EXAMPLES.

Example 1.

10 In this example, the formulation of a gel used in the method according to the invention is described, used particularly in examples 2, 3 and 4.

This gel, referred to as "Gel-1" is a gel which composition is as follows:

- 20% by mass of alumina;
- 80% by mass of deionized water.

15

The alumina is Aeroxide® Alu C alumina marketed by EVONIK INDUSTRIES® which is a pyrogenic alumina with a specific surface area of 100 m²/g (BET).

This gel is prepared according to the following protocol:

The deionized water is first weighed in a suitable container.

20 The alumina, in a proportion of 20% by mass, is then gradually added to the deionized water, under stirring using a mechanical stirrer, equipped with a three-blade stirrer, at a speed of 200 rpm, for 3 to 5 minutes.

As alumina is added, the viscosity of the stirred medium increases.

25 The rotational speed of the stirrer is therefore also gradually increased as the viscosity of the stirred medium increases, to reach about 400 to 600 rpm when all the alumina has been added, making sure that there is no splashes.

The gel referred to as "Gel-1" thus prepared is finally kept under stirring for 5 minutes, and allowed to rest for a time of at least one hour before the use thereof.

30

Example 2.

In this example, it is shown that the gel, referred to as "*Gel-1*" has the rheological properties required for the use thereof in the method according to the invention.

A rheological study of the gel referred to as "*Gel-1*", prepared in example 1 was therefore carried out and shows that this method is adapted to:

- 5 - use by spraying in the form of fine droplets.
- fixation of the particles taken up, captured on the walls (floor, ceiling and walls) of the room to be decontaminated.

10 For the gel to be able to be used with a spraying method, it must have the properties of a rheofluidifying, thixotropic fluid.

For the gel to enable fixation of the captured, taken up, particles on the walls, it must have a very short viscosity recovery time (less than one second), and have a threshold stress (typically greater than 10-15 Pa).

15 Various rheological measurements were made using a TA Instruments® DHR1 rheometer in "*Vane*" geometry and are presented in this example.

Firstly, the viscosity of the gel was measured as a function of the shear rate.

20 After pre-shearing for 1 minute at a shear rate of 20 s^{-1} , followed by 1 minute of rest (no shearing), a continuous shear rate gradient, ramp ranging from 0.01 s^{-1} to 1000 s^{-1} over a total time of 300 seconds is applied. 10 viscosity measurements per decade are carried out.

Figure 2 gives the variations of the viscosity (Pa.s) of the gel referred to as "*Gel-1*" as a function of the shear rate (s^{-1}) for shear rates between 0.01 and 1000 s^{-1} . A linear drop (in logarithmic scale) of the viscosity with the shear rate is observed, characteristic of the behavior of a rheofluidifying fluid.

25 The gel referred to as "*Gel-1*" therefore has a high viscosity at low shear rates, namely at rest, and a very low viscosity when it is strongly sheared, enabling it to be sprayed.

30 Then, the gel is strongly sheared at 1000 s^{-1} , for 30 seconds, then a shear rate of 0.01 s^{-1} is directly applied, also for 30 seconds. Figure 3 shows the variations of the viscosity of the gel as a function of time. It is observed that the gel recovers its viscosity very quickly following a high shear, with a viscosity recovery time of the order of one second. This means

that the sprayed droplets will recover their viscosity almost instantaneously at the nozzle outlet.

Finally, a low shear rate (0.01 s^{-1}) is applied to the gel referred to as "*Gel-1*" constantly so as to deform it from rest and thus determine the flow threshold thereof.

5 Figure 4 represents the shear stress value as a function of deformation of the gel referred to as "*Gel-1*". Firstly, the stress increases significantly as a function of deformation, the material is in the solid regime (elastic deformation). A change of behavior is then observed, the stress attains the flow threshold and the material changes to the liquid regime (stationary flow). The threshold stress corresponds to the stress at the flow
10 threshold of "*Gel-1*", i.e., 30 Pa. Such a threshold stress value enables "*Gel-1*" to adhere to a wall, particularly to a vertical wall and then to hold on this wall for a thickness of a few millimeters, for example for a thickness between 0 and at least 2 mm.

This thus enables the fixation of the contaminants previously taken up in the atmosphere.

15 In conclusion, this example shows that "*Gel-1*" has actually all the rheological properties required for the spraying thereof in the form of fine droplets with a view to decontaminating an atmosphere contaminated with contaminants in suspension, then for fixing the contaminants taken up, captured, on the walls (floor, ceiling and walls) of the room to be decontaminated.

20

Example 3.

In this example, the spraying of the gel referred to as "*Gel-1*" described in example 1 in the form of fine droplets is described, in other words, the creation of a mist consisting of fine droplets of the gel referred to as "*Gel-1*" is described.

25 The laboratory spraying system, device used in this example is similar to that represented in Figure 1, and which has already been described above.

This device is a unique laboratory apparatus not having any technological novelty, but which is used differently than usual.

30 As already described above, a mist of gel consisting of fine droplets is created by applying at the level of the spray nozzle of the system a fluid pressure and an air pressure.

Spraying is carried out in a defined volume, namely under a fume cupboard.

Once sprayed, the droplets from the nozzle are recovered on an adhesive carbon patch deposited in a corner of the volume wherein the mist was sprayed.

After drying, the unitary size of the generated droplets can thus be observed.

5 Figure 5 is an SEM Microscope image of the dry droplets thus generated.

It is observed in Figure 5, that dry droplets the size of which is defined by the diameter thereof is of the order of 40 μm are obtained.

It should be noted that the applied pressure values appear to only have very little influence on the size of the droplets.

10

Example 4.

In this example, which illustrates the method according to the invention, a large enclosed volume, namely an enclosed volume of 4.5 m^3 is filled with a mist of the gel referred to as "Gel-1" prepared in example 1, then a non-powdery solid waste is formed with this gel on the walls defining this volume. This solid waste can be recovered by vacuuming (it is vacuumable, suctionable).

15

The spraying system used in this example to create the mist is the same as that used in example 3, it is similar to the system represented in Figure 1, and which has already been described above.

20

It was then possible to form a gel mist within an enclosed volume defined inside the walls of a parallelepipedic box of 4.5 m^3 (see Figure 6).

Thus, in the same way as a mist composed of water droplets, the gel mist thus generated can, in a first phase, take up, then draw down, aerosols of contaminants in suspension in a large volume.

25

In a second phase, the droplets trapping the aerosols of contaminants are deposited and aggregated on the walls of the enclosed volume thanks to the rheological properties of the gel, described in example 2. In this way, according to the spraying time and speed, a more or less substantial layer of gel is formed on the walls of the enclosed volume. The gel then dries like a conventional vacuumable, suctionable gel and is fractured into a solid

waste of millimetric size trapping the aerosols of contaminants taken up and thus preventing the resuspension thereof.

The thicker the layer of gel formed by aggregation of the gel droplets, the larger the size of the solid waste.

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CLAIMS

1. Method for decontaminating a volume of a gaseous medium contaminated with contaminating species in suspension, said volume of a gaseous medium being in contact with at least one surface of a solid substrate, said method comprising the following successive steps:

a) fine droplets are sprayed in said volume of a gaseous medium, thus forming a mist, of an inorganic gel consisting of a colloidal solution comprising an inorganic viscosifying agent, and a solvent;

b) the contaminating species in suspension are captured, taken up by said inorganic gel droplets;

c) the inorganic gel droplets containing the captured contaminating species in suspension deposit, settle on said surface of the solid substrate;

d) the gel is kept on the surface of the solid substrate at least for a sufficient time for the gel to dry and form a dry and solid residue containing the captured contaminating species in suspension;

e) the dry and solid residue containing said captured contaminating species in suspension is recovered.

2. Method according to claim 1, wherein the gaseous medium is air.

3. Method according to any one of the preceding claims, where the volume of a gaseous medium is an enclosed volume defined by walls, such as a floor, a ceiling and walls, forming said surface, the mist of fine droplets fills the entire enclosed volume, and the fine droplets of the inorganic gel containing the captured contaminating species in suspension deposit, settle on at least one of the walls, preferably on all the walls.

4. Method according to any one of the preceding claims, wherein the fine droplets have a size defined, by the greatest dimension thereof, such as a diameter, from 10 to 1000 μm , preferably from 20 to 200 μm .

5. Method according to any one of the preceding claims, wherein said contaminating species in suspension are in the form of solid particles, liquid particles, or in the form of molecule species.

5 6. Method according to any one of the preceding claims, wherein the contaminating species are selected from chemical, biological, nuclear or radioactive contaminating species.

10 7. Method according to any one of the preceding claims, wherein the contaminating species are contaminating species that are radioactive, and/or chemically toxic, and/or toxic due to the form, shape, and/or the size thereof.

15 8. Method according to claim 7, wherein the toxic contaminating species due to the form, shape, and/or the size thereof, are contaminating species in the form of solid particles such as microparticles, or nanoparticles, for example in the form of fibers such as microfibers or nanofibers, in the form of nanotubes, or in the form of crystals such as nanocrystals.

20 9. Method according to any one of claims 6 to 8, wherein the contaminating species are selected from metals and metalloids in metal, metalloid, or ionic form, preferably from so-called "heavy metals", and toxic metals and metalloids in metal, metalloid or ionic form; the compounds of these metals and metalloids such as organometallic compounds, metal salts, metal oxides, metal carbides, etc.; ceramics; wood; cereals; flour; and glasses, for example in the form of glass wool.

25 10. Method according to claim 9, wherein the contaminating species is asbestos.

11. Method according to any one of the preceding claims, wherein the colloidal solution further comprises one or several component(s) selected from the following components:

- a surfactant;
- 30 - an active decontamination agent;

- a trapping agent ("*getter*") to trap the gaseous contaminating species, particularly the toxic or explosive gaseous contaminating species, such as hydrogen;

- a contaminating species extracting agent;

- a contaminating species fixing agent;

5

- a coloring agent.

12. Method according to any one of the preceding claims, wherein the colloidal solution, comprises, preferably consists of:

10

- 1% to 30% by mass, preferably 1% to 25% by mass, more preferably 5% to 25% by mass, better 8% to 20% by mass, with respect to the mass of the gel, of at least one inorganic viscosifying agent; and one or several component(s) selected from the following components, in the following proportions:

- 0.1% to 2% by mass with respect to the mass of the gel, of at least one surfactant;

15

- 0.1 to 10 mol/L of gel, preferably 0.5 to 10 mol/L of gel, more preferably 1 to 10 mol/L of gel, and better from 3 to 6 mol/L of gel, of at least one active decontamination agent;

20

- 0.1% to 5% by mass, with respect to the mass of the gel, of at least one trapping agent ("*getter*") to trap the gaseous contaminating species, particularly the toxic or explosive gaseous contaminating species, such as hydrogen;

- 0.1% to 5% by mass with respect to the mass of the gel, of at least one contaminating species extracting agent;

- 0.1% to 5% by mass with respect to the mass of the gel, of at least one contaminating species fixing agent;

25

- 0.01% to 10% by mass, preferably 0.1% to 5% by mass, with respect to the mass of the gel, of at least one coloring agent;

- and the remainder of solvent.

30 13. Method according to any one of claims 1 to 10, wherein the colloidal solution, comprises, preferably consists of:

- 1% to 30% by mass, preferably 1% to 25% by mass, more preferably 5% to 25% by mass, better 8% to 20% by mass, with respect to the mass of the gel, of at least one inorganic viscosifying agent;
- and the remainder of solvent.

5

14. Method according to any one of the preceding claims, wherein the inorganic viscosifying agent is selected from metal oxides such as aluminas, metalloid oxides such as silicas, metal hydroxides, metalloid hydroxides, metal oxyhydroxides, metalloid oxyhydroxides, aluminosilicates, clays such as smectite, and mixtures thereof.

10

15. Method according to claim 14, wherein the inorganic viscosifying agent consists of one or several alumina(s).

15

16. Method according to claim 15, wherein the alumina(s) represent(s) from 5% to 30% by mass, preferably from 8% to 17% by mass with respect to the total mass of the gel.

17. Method according to claim 15 or 16, wherein the alumina(s) is (are) selected from pyrogenic aluminas, preferably from fine-grained pyrogenic aluminas.

20

18. Method according to any one of claims 11 to 17, wherein the active decontamination agent is selected from bases such as sodium hydroxide, potassium hydroxide, and mixtures thereof; acids such as nitric acid, phosphoric acid, hydrochloric acid, sulfuric acid, hydrogen oxalates such as sodium hydrogen oxalate, and mixtures thereof; oxidizing agents such as peroxides, permanganates, persulfates, ozone, hypochlorites such as sodium hypochlorite, cerium IV salts, and mixtures thereof; quaternary ammonium salts such as hexadecylpyridinium (cetylpyridinium) salts, such as hexadecylpyridinium (cetylpyridinium) chloride; reducing agents; and mixtures thereof.

25

30

19. Method according to any one of claims 11 to 18, wherein the surfactant is selected from non-ionic surfactants such as block, sequenced copolymers such as ethylene

oxide and propylene oxide block copolymers, and ethoxylated fatty acids; and mixtures thereof.

20. Method according to any one of claims 11 to 19, wherein the trapping agent ("getter") is selected from very high specific surface area solids which contain active surface sites, such as porous carbons, for example active carbons; cage materials particles, such as zeolite and MOF particles; and mineral oxide particles capable of reacting with the contaminating species to be trapped and more specifically with hydrogen, such as manganese oxides (MnO_3 , Mn_2O_3 , Mn_2O_4) and noble metal oxides, for example Ag_2O or RuO_2 .

21. Method according to any one of claims 11 to 20, wherein the contaminating species extracting agent is selected from inorganic adsorbents such as zeolites, clays, phosphates such as apatites, titanates such as sodium titanates, and ferrocyanides and ferricyanides.

22. Method according to any one of claims 11 to 21, wherein the contaminating species fixing agent is selected from organic resins, such as polyurethane resins, epoxy resins and acrylic resins.

23. Method according to any one of claims 11 to 22, wherein the coloring agent is selected from organic dyes and mineral pigments, preferably micronized, such as metal(s) and/or metalloid(s) oxides, metal(s) and/or metalloid(s) hydroxides, metal(s) and/or metalloid(s) oxyhydroxides, metal(s) ferrocyanides and ferricyanides, metal(s) aluminates, and mixtures thereof.

24. Method according to any one of the preceding claims, wherein the solvent is selected from water, organic solvents and mixtures thereof.

25. Method according to any one of claims 11 to 24, wherein the surface of the solid substrate is contaminated with at least one contaminating species referred to as a surface contaminating species located on said surface and optionally under said surface in the depth of the substrate, the gel contains a decontamination agent, and during step d) the gel is kept, maintained on the surface at least for a sufficient time for the gel to destroy and/or inactivate and/or absorb the surface contaminating species, and for the gel to dry and form a dry and solid residue containing said surface contaminating species and the contaminating species in suspension taken up, captured by the gel.

26. Method according to any one of the preceding claims, wherein the solid substrate is made of at least one solid material selected from metals and metal alloys such as stainless steel, painted steels, aluminum, and lead; polymers such as plastics or rubbers such as polyvinyl chlorides or PVCs, polypropylenes or PPs, polyethylenes or PEs particularly high-density polyethylenes or HDPEs, polymethyl methacrylates or PMMAs, polyvinylidene fluorides or PVDFs, polycarbonates or PCs; glasses; cements and cement materials; mortars and concretes; plasters; bricks; natural or artificial stone; ceramics.

27. Method according to any one of the preceding claims, wherein the amount of gel deposited is from 100 g to 2000 g of gel per m² of surface, preferably from 500 g to 1500 g of gel per m² of surface, more preferably from 600 g to 1000 g of gel per m² of surface.

28. Method according to any one of the preceding claims, wherein during step d), the drying is carried out at a temperature from 1°C to 50°C, preferably from 15°C to 25°C, and at a relative humidity from 20% to 80%, preferably from 20% to 70%.

29. Method according to any one of the preceding claims, wherein the gel is kept, maintained on the surface for a time from 2 to 72 hours, preferably from 2 to 48 hours, more preferably from 3 to 24 hours.

30. Method according to any one of the preceding claims, wherein the dry and solid residue is in the form of particles, for example flakes, of a size from 1 to 10 mm, preferably from 2 to 5 mm.

5 31. Method according to any one of the preceding claims, wherein the dry and solid residue is removed from the solid surface by brushing and/or vacuuming, suctioning.