Chemical Hazard in FRP Pleasure boats' Manufacturing

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ABSTRACT

The work aims to discuss measures to reduce risks associated with the workers' exposure to harmful chemical agents in FRP manufacturing processes. Data on workers' exposure were collected directly on the site plant of a few manufacturers of fiberglass pleasure boats and other FRP components. Work focuses on various stages of progressive study: I) study of the molding manufacturing process, workplace, structures, tools, materials and plants in the different companies; II) statistical study of the use of Personal Protective Equipment; III) environmental and personal sampling campaign. The study phase I is preliminary to the following. It allowed to identify, for each operators category, the risk factors to which each category is most exposed. Styrene and other VOCs are the main chemical risk factor on which attention has been paid for resins and gelcoat workers. The phase study II about the use of PPE leads to define evolution models in the use of PPE in relationship with room temperature and referring to Behaviour-Based Safety techniques to increase the percentage of use of PPE. The phase study III leads to define what the critical exposure moments are for workers, specially the processes when resin or gelcoat are sprayed. From this stage, intervention proposals arise measured to reduce risks.

Keywords: Chemical hazard, FRP manufacturing, Personal Protective Equipement, Behaviour-Based Safety, Styrene and VOCs exposure.

INTRODUCTION

"*What's the most disgusting thing that we breathe?*". The word-by-word analysis of the meaning of this question by an operator to the writer during the study phase of the manufacturing process leads to a good starting point for the description of the dissertation. First, it's clear that a risk to workers' health and safety exists, during the production of fiberglass products. *The "most disgusting thing* suggests" that there is more than one hazard, and in particular chemical hazards, that is related to the intrinsic properties of the substances used in the molding parts process of fiberglass. The fact that the operator uses the word *breathe* explicit the notion that chemical risk materializes mostly in airborne harmful substances and that operators are exposed to these substances in some way. A superficial glance at the literature is enough to argue that the answer to the operator's question consists in volatile organic compounds, specially the ones coming from resins used for the production of molded parts, and fiberglass dusts that developed as a result of cutting and trimming of components. Determining in what quantity they may be found in the workplace and estimating how workers can be exposed is the topic of the present work. To assess the exposure of workers to toxic substances it's necessary to study, among others, the use of protection methods that they have access to and investigate the problems that cause the not utilization of PPE if necessary. An example of this process has been the attempt to understand by some operators the reasons why at that time, during processing with a spray of resin, they were not wearing the mask for the airways protection. The effect of the question was that immediately operators wore the masks and claimed that they always use them. By paraphrasing from quantum physics, one could say that it's impossible to measure a quantity of a system without perturbing it. We must therefore take into account the possibility that some behavior of workers during the study may have suffered alterations merely with the fact that there was an outside observer. Too often, safety is seen as something detached from the production process, we have to deal with it for sure, but giving priority in optimizing the production. In a safety culture, improved working conditions, both in the sense of ergonomics, either to health respect, is part of the optimization itself of the manufacturing process. The actions proposed in this work will therefore be aimed at an improvement of the manufacturing process in the aspects of workers' safety and health.

MATERIALS AND METHODS

The structure of the present work is focused on various stages of a progressive study which are listed below.

I - Study of the molding manufacturing process, workplace, structures, tools, materials and plants

At this stage it's possible to classify the study for type of processing and type of workers. The processing categories taken into account are the following: hand lay-up; spray-up; gelcoat deposition (hand and spray); contour cutting; pre-finishing; further lower processing. The categories of operators are: resins workers; gelcoat workers; contour cutters; pre-finishing workers; further operators potentially less exposed. The main substances used during lay-up on which the work is focused are: glass in the form of woven fabrics, non-woven fabrics, roving; polyester resins; polyester-based gelcoat; catalyst MEKP; acetone. Referring to the production plant used as a case study in this work it's needed to point out that the main lay-up rooms were equipped with general ventilation system. There were no localized ventilation systems. There were some segregated cabins of various dimensions equipped with their own ventilation plant.

II - Statistical study of the use of Personal Protective Equipment

Statistical study of the use of Personal Protective Equipment, required by the company to workers, for each processing category, the room temperature varying. Observations were performed over a period of time ranging from April to July, from 06.00 to 22.00. The room temperature measured was in a range between a minimum of 17°C and a maximum of 34°C. PPE concerned were: respiratory protection from airborne volatile compounds and dusts, eye protection, hearing protection, hand protection, safety shoes, body protection from chemicals. For each category of operators graphs of the utilization of every kind of PPE in relation to temperature variation were drawn and are reported below.

III - Environmental and personal sampling campaign

For each type of worker the qualitative exposure to major risks chrono-daily tables are drawn up, associated with FRP processing. Qualitative exposure values are then replaced with values obtained with PID (photo-ionization detector) samples. Main chemical risk factors for workers' health and safety are volatile organic compounds (especially styrene) and airborne dusts. Chrono-tables allow to evaluate the pollutant TWA (Time-Weighted Average) and the STE (Short Term Exposure) concentration for each substance and compare them with the TLV (Threshold Limit Values) in force in the case study's country (Italy). For styrene TLV-TWA is 20ppm and TLV-STEL is 40ppm. Because of the economic crisis, carrying out the sampling campaign in the company of the preliminary study has not been possible. So we decided to apply the campaign on two companies which took over the same (or similar) types of fiberglass manufacturing. The two companies have become available to host detections of VOCs during processing they perform. The Multi-PID 2 detector was set to record the concentration values of styrene in air in ppm at intervals of 30 seconds of each other. For each 30-second interval the minimum value measured, the maximum level and the average are recorded. Data collected for every working step and for each company are then statistically analyzed according to the UNI EN 689.

Company A

The company produces small fiberglass boats (dinghies). That means that the production process is very close to the one of main case study for the type of product and materials used. The processing comparable with the main case study are:

- Hand-lay-up, roller impregnation
- Other assembling operations
- Breaks
- Gelcoat spray

Samplings were carried out for type of working, placing the instrument close to the operator respiratory tract.

Table 1: summary of sampling results in company A.

Company A	**Total sampling time**	**Mean styrene**	**Std. dev.**	**c.v.**	**Geometric mean styrene**
	min.	ppm	ppm	-	ppm
Hand lay-up	59.5	87.4	35.28	0.40	80.4
Others	70.5	42.0	24.57	0.58	35.7
Gelcoat spray	15.5	56.7	30.49	0.54	51.0
Breaks	19.5	6.0	7.33	1.23	-

Company B

The company manufactures fiberglass tanks and pipes, so it's close to the main case study for the size of the artifacts. The processing comparable with the main case study are:

- Hand-lay-up, roller impregnation
- Spray-up
- Bubble-breaking
- Other assembling operations
- Breaks.

Table 2: summary of sampling results in company B

Company B	**Total sampling time**	**Mean styrene**	**Std. dev.**	**c.v.**	**Geometric mean styrene**
	min.	ppm	ppm		ppm
Hand lay-up	61.5	23.1	20.84	0.90	17.1
Spray-up	28.0	105.8	82.79	0.78	80.5
Bubble-breaking	39.5	44.3	25.37	0.57	38.5
Others	69.5	11.2	4.34	0.39	10.5
Breaks	6.5	3.3	4.02	1.24	2.1

After collecting them, the sampled data are replaced within the chrono-daily tables for each type of worker. Each qualitative value of any interval is replaced by a concentration value randomly chosen between the mean values detected by the instrument of each work session (of the same type of the replacement). For each type of different operator, for any iteration of random numbers extraction chrono-quantitative tables of exposure are obtained. From these simulations we extract the TWA, and follow the procedure described in Appendix C of the UNI EN 689:1997.

Hulls resin operators

The average TWA calculated with 20 simulations is 39.5 ppm with a standard deviation of 1.35 ppm and that means that the TLV-STEL is not met and, as a consequence, measures to reduce exposure are required.

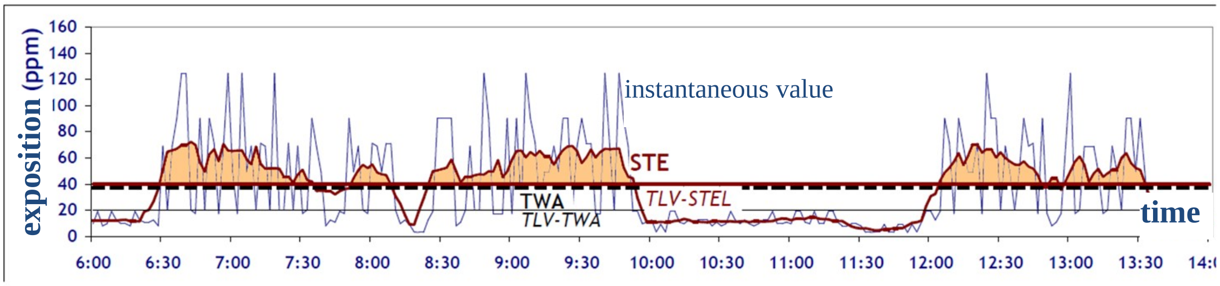

Figure 1. Example of hulls laminators chrono-daily table.

Decks resin operators

The average TWA calculated with 20 simulations is 32.8 ppm with a standard deviation of 0.86 ppm. The TLV-STEL is not met, so measures to reduce exposure are required.

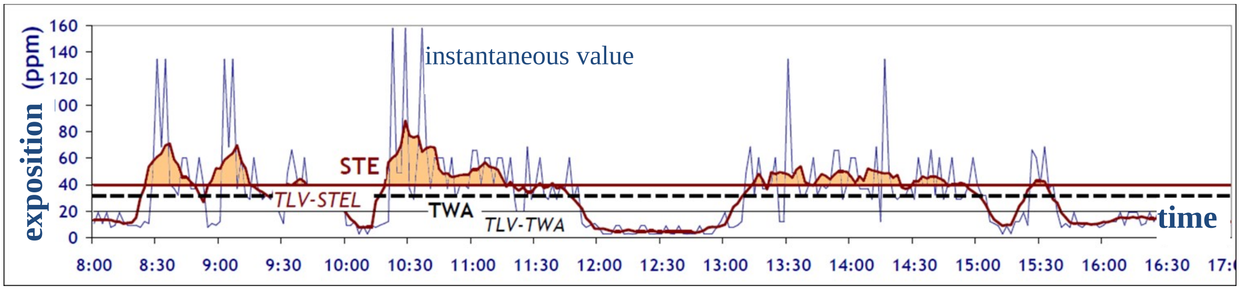

Figure 2. Example of decks laminators chrono-daily table.

Gelcoat operators

The average TWA calculated with 20 simulations is 20.7 ppm with a standard deviation of 0.57 ppm. The TLV-STEL is not met. Measures to reduce exposure are required.

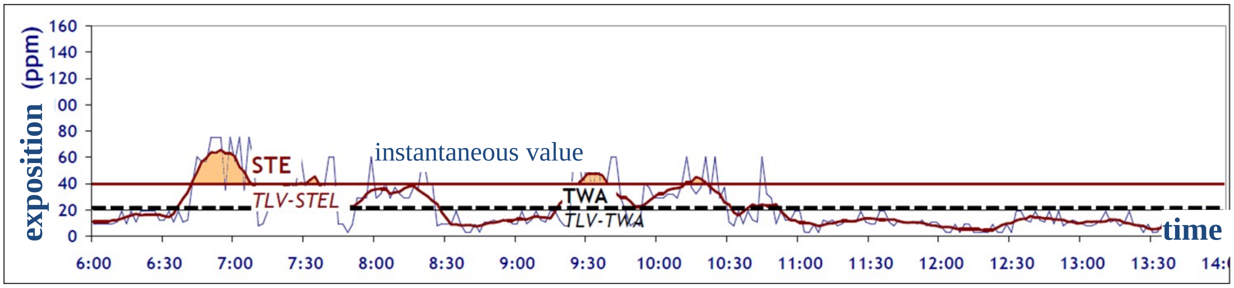

Figure 3. Example of gelcoat operators chrono-daily table.

RESULTS AND DISCUSSION

1st level interventions

The first-level interventions to minimize or eliminate the risk may concern different objects.

- Substances: resins and gelcoats can be replaced with equivalent low styrene content or low styrene emission. Resins with low styrene emission (LSE) let the concentration of styrene in the air during the static phase of the process be less for the fact that they create a superficial film when the mold is left at rest. Resins with low styrene content (LSC) are more effective in the reduction of the emission of styrene during the dynamic phase of the process. There are on market gelcoats low styrene content. The use of resins and gelcoats LSE and LSC is even more effective for working on very opened molds. Below a graph of the emission of styrene in time comparing standard resins and resins LSE, LSC and combined LSE&LSC.

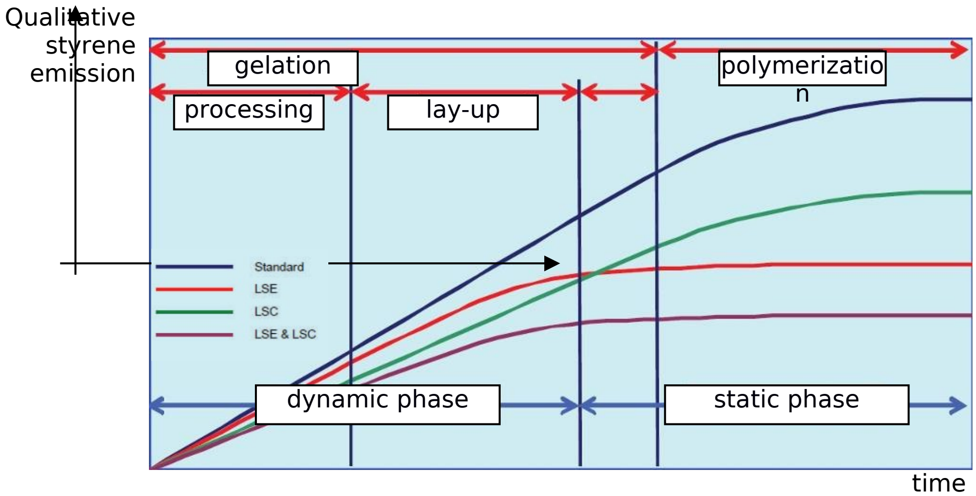

Figure 4. Comparison between different types of resins. (CEFIC, EuCIA. 2011)

- Process: possible changes to the production process concern in particular the equipment used. The gelcoating robot, if already present in the factory, may allow a significant reduction of spray-gelcoating operators’ exposure, if functional. It can be used to gelcoat more simple geometry pieces, such as hulls, linked to a redesign of the factory layout.

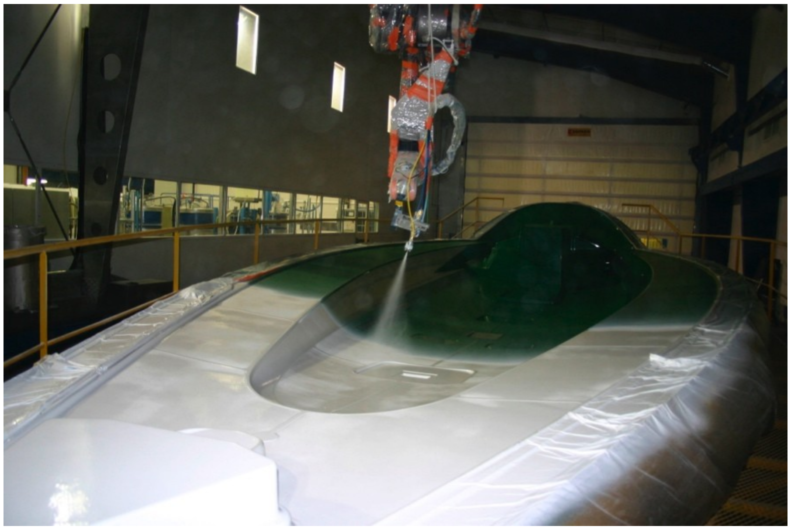

Figure 5. Gelcoat robot in action on a simple deck in cabin. No operators needed nearby the spray

- Environment: above the aspiration ceiling panels fiberglass dusts always settles and accumulates which, as a result of vibrations, falls cascade also over the operators who are working. These accumulations of dusts can be removed at the end of the deburring shift with a vacuum cleaner. Cleaning can also have an effect on the efficiency of the extraction system.

- Organization: it's possible to make adjustments on operating procedures. To limit the exposure of workers to styrene vapors during spray-up operations it's necessary to ensure that there are no operators downwind (with respect to the ventilation system) of the spray gun or in the resin spray direction.

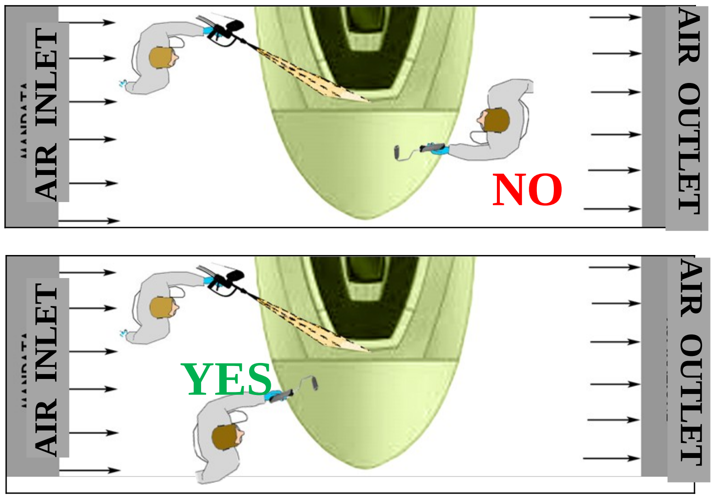

Figure 6. Wrong and correct spray-up operators position.

Sometimes, especially when the spray-up machine is already in use, to do more quickly, fabrics to be deposited by hand lay-up are wetted with resin spray. This can be avoided by impregnating fabrics with a roller or brush dipped in resin to which it was previously added the catalyst (hand lay-up with roller impregnation). The industrial fans that are used to improve operators' working conditions or to accelerate the removal of vapors from the laminated parts must be directed so as to promote the creation of air flows from the blowing to the aspirating elements. Acetone must be used only to clean tools, not even operators' skin. For that purpose there are specific products for the removal of resins and coatings from hands and skin. These products can be placed inside the dispenser (such as hand-washing soap) directly in the molding rooms, next to a bucket of water, which is changed sometimes during the day, for rinsing.

Figure 7. Example of hand cleaner product

Behavior-Based Safety

Regarding the case studied, an example of a goal to obtain directly connected with the worker behavior, is the proper use of PPE. The effective way to operate and change the behavior of workers is to adopt a B-BS (Behavior-Based Safety) protocol. B-BS is a natural science that originates from Behavior Analysis. Any behavior is not from within the worker but it's determined by external contingencies, from the environment to the worker. In this regard, in the first half of the 1900s B.F.Skinner developed the three-term contingency model also known as A-B-C, where A stands for Antecedents, B for Behavior and C for Consequences. This model states that behavior is evoked by external stimuli that precede it (antecedent contingencies) and modified by external stimuli consecutive to behavior that increase or decrease the probability of emission (consequences). To evoke and modify any behavior it's enough to operate on antecedents and consequences to such behavior. The consequent stimuli can be of four types:

- *Positive reinforcement* involves hiring a pleasant stimulus to the worker. Increases the probability of emission of the safety behavior and optimizes the parameters descriptive of behavior.
- *Negative reinforcement* involves removing a not pleasing stimulus to the employee. Increases the probability of emission of the behavior but it brings the parameters up to a required minimum level.
- *Punishment* involves hiring an unpleasant stimulus.
- *Penalty* involves removing a pleasant stimulus. Together with the punishment, they decrease the probability of emission of the behavior.

The consequent stimuli not delivering leads to extinguish the behavior and it is called *extinction*. The scheme works best for safety is the one formed by positive reinforcement of safety behaviors and extinction of unsafe behaviors (punishment and penalties used only for the most severe cases). The positive reinforcement can be of different types. Those consumables (eg granting of more breaks), those symbolic (e.g. token system with deferred bonuses), those social (e.g. social praise, compliments). To be effective, the delivery of positive reinforcement must take place immediately after the behavior (if this is not possible it is necessary to anticipate verbally the future provision of reinforcement), should be adjusted so that it is pleasant for the people who receives it and varied. It is also necessary to eliminate the antagonists to reinforcement provided consequent stimuli. This system eventually leads to the creation of a culture of safety in which all the actors in the company are potential providers of positive reinforcement and all subjects reinforce same safety behaviors. As an indirect effect of B-BS there is the improvement of the corporate atmosphere with a consequent improvement in productivity. (F. Tosolin, 2012)

2nd level interventions

The second level interventions in order to restrict contact with the risk may relate to different objects.

- Environment: it's possible to design a redefinition of the layout of the production site which can meet various requirements. It's necessary to implement, as far as possible, the segregation of spray lay-up and spray gelcoat operations.
- The general ventilation system should be kept active all the time in the presence of workers in the factory, even during breaks.
- Equipment: the optimal solution for the reduction of the workers exposure is the design of a system of localized suction on each mold, of push-pull type. The strategy can be adopted for the molds of the hulls and it consists on the introduction of fresh air from the bow and air extraction to the stern. A similar situation is valid for the decks lamination. A schematic picture of the configuration of this extraction system is reported below.

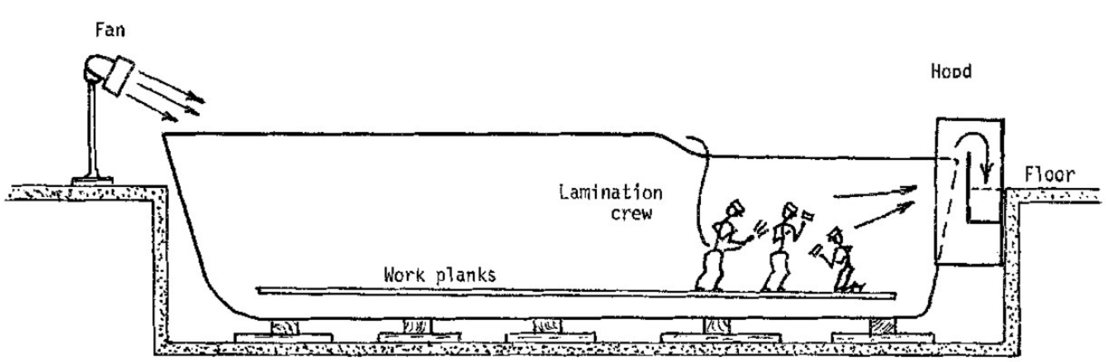

Figure 8. schematic view of a push-pull plant. (W.F. Todd, NIOSH. 1983)

3rd level interventions

Third-level interventions aimed at limiting workers' exposure may relate to different objects.

- Environment: wherever gelcoat robot is in use, staff segregation is feasible. It's possible to create a completely isolated cabin from the gelcoat area that allows the operator to observe the behavior of the robot and operate any controls.

- Organization: the adoption of additional PPE shall be subject to a system of B-BS permitting the proper use of those already adopted by the company.

Where there is the existence of suspended loads must consider the use of protective headgear from falling objects or pieces. During the operations of resin or gelcoat spray is necessary that operators carrying out these tasks and all the surrounding ones are wearing glasses for eye protection, where this is not already the case. Groups of workers who work the afternoon shift (14:00 to 22:00) are potentially more exposed to a higher concentration of styrene due to the crosslinking of the pieces laid-up during the morning. It is therefore important that operators are often assigned to work shifts rotated between morning and afternoon.

Morning shift	06:00-14:00
Afternoon shift	14:00-22:00

Table 3: summary table of interventions with priority, effectiveness and feasibility.

Hazard	Intervention		Priority	Effectiveness	Feasibility
	Level	intervention	A>B>C>D		
spray-up (styrene)	1st level:	no operators downwind resins spray	A	exposition reduction.	linked with education, no cost.
	2nd level:	segregation, if possible, in cabin	A	concentration reduction in other rooms.	installation of extraction system in cabin, medium-high cost.
		push-pull plants' design above decks' molds	A	very strong exposition reduction.	immediate feasibility, high cost.
	3rd level:	eye protection adoption	A	protection from resins squirts and glass fibers.	linked to B-BS, very low cost.
gelcoat spray (styrene)	1st level:	implementation of the gelcoat robot	A	exposition elimination during hulls' gelcoat, operators' exposition overall reduction.	linked to layout change, high cost.
	2nd level:	gelcoat spray cabin segregation.	A	very high concentration reduction	not feasible for largest molds, no cost.
	3rd level:	operator cabin building where robot is placed	A	exposition elimination for the robot attendant	linked to layout change, low cost.
unsafe behaviors	1st level:	introduction of a B-BS protocol (PPE increase of use).	A	injuries reduction, birth of safety culture and values, improvement of the working environment and performances.	long-lasting process, initial cost and return in term of saving on compensation, damages, and stops and income on improving performance.
styrene (general)	1st level:	use of LSE and/or LSC resins.	B	emission reduction.	not economically convenient to date
		long-handled bubble breaker roller	B	exposition reduction.	immediate feasibility, very low cost.
		fabrics for hand-lay-up not soaked by spraying, by roller instead	B	emission reduction.	immediate feasibility, no cost.
		fans geared toward the suctions elements, not the flowing elements	B	concentration in rooms slight reduction.	immediate feasibility, no cost.
	2nd level:	pre-finishing workers away from resins operations (no need to stay there)	B	exposition elimination for pre-finishing workers.	linked to layout change, low cost.
		always on general ventilation system	B	strong concentration reduction especially during static phases	immediate feasibility, low cost.
	3rd level:	morning/afternoon shift rotation	B	weekly exposition reduction.	immediate feasibility, no cost.
acetone	1st level:	use of handwash products from resins and gelcoat	C	dermal exposition elimination-	immediate feasibility, low cost.
dusts	1st level:	removal of fiberglass dusts build-up	C	dusts concentration reduction, improvement of the functioning of ventilation system.	immediate feasibility, very low cost.
working conditions	1st level:	long-handled bubble breaker roller	C	immediate elimination of the discomfort rolling position	immediate feasibility, very low cost.

Priority of interventions is based on carried out samplings, for the risks concerning styrene.

CONCLUSIONS

The study carried out applies not only to manufacturing in the marine field, but also to all industries who operate with fiberglass in the same manner. The study itself has not been linked to a single production reality but represents the research outcome in three different production companies. The effectiveness of the proposed interventions has been evaluated only qualitatively and theoretically. A comprehensive study that allows to quantitatively evaluate the effectiveness of interventions must provide this scheme of work: Phase I / Phase II / Phase III / Intervention proposal and application / Phase II bis / Phase III bis / Effectiveness of interventions review. Risks to health and safety of workers in a yard who uses fiberglass are not limited to the mere presence of styrene. Other risks to workers health are the presence of catalysts and other products and intermediates potentially toxic and the dispersion in the environment of glass and fiberglass dusts and fibers from machining. A comprehensive study on the risks must also consider the ones associated with such risk factors. The presence at the workplace of flammable or explosive substances is a risk to safety of workers and therefore the risk must be assessed and brought to the *as low as reasonably achievable* level.

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