

NPP decommissioning: a methodology to evaluate the gaseous pollution produced by hot cutting processes

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Abstract

A right methodology to determine preventively gaseous emissions arising from thermal cutting process is essential to properly evaluate pollution in decommissioning a NPP. Said assessment can be related, in addition, to other diverse situations. In this paper, the estimated values of the pollution involved with plasma torch and oxyacetylene arc cutting processes are presented, in particular relating to the volatilized material, the volume of particles per hour, and the concentration at the inhalation by workers and in the cutting room. These processes have been carried out in an experimental campaign at the Caorso nuclear power plant (CaNPP), currently under dismantlement. Components being cut are not activated, e.g. pipes and plates in carbon steel, from different parts of coolant system. Considerations are reported to evaluate the dilution between emissions and air at the inhalation and suggestions follow to safely perform the mentioned cutting procedures.

Keywords

decommissioning, plasma torch cutting, oxyacetylene arc sectioning, gaseous emissions, environmental effect

1. Introduction

NPPs decommissioning requires, in general, the adoption in situ of specific disassembling technologies for metal component segmentations and removal, such as cutting and splitting and the improvement of various decontamination processes. As the activities of decommissioning, in the next fifteen-twenty years, are estimated to be superior to those connected with the construction of new plants, a cautious analysis of the related actions is indispensable

in addition to the most appropriate preparation of the working personnel. A range of health hazards, moreover, should be postulated for workers engaged in metal cutting procedures. The problem of the gaseous pollution produced by these processes, in fact, is a main concern and it should be appropriately analysed.

CaNPP, the largest Italian nuclear facility equipped with an 870 MW_e boiling water reactor BWR of the second generation, operated for almost seven years, producing ~29 GkWh. The connection with the Italian electric grid was set in 1978, while the production of electric power started in 1981. In 1986 the plant was stopped for fuel recharge, never restarting (it was shut down in 1987) due to the Italian poll that, after the Chernobyl event, obliged the Italian exit of nuclear power use.

Decommissioning activities of CaNPP began in 1999 and the decontamination of the primary circuit was completed in 2004. The dismantlement and the removal of the turbo-alternator from the turbine hall were completed in 2006, while the demolition of the auxiliary cooling tower was completed in 2008. The dismantling and decontamination operations of the gaseous discharge treatment plant have started in February 2010, with the demolition of the chimney. As CaNPP was not planned and built considering in advance also its decommissioning, the operations related to dismantling and cutting can involve complications due to reduced manoeuvrability, narrowness of the places and inadequacy of lighting. Additional problems

arise, sometimes, in achieving and maintaining a suitable air circulation in the sites under dismantlement. The major form of exposure in cutting surface-contaminated materials, in fact, can be inhalation. Plasma torch and oxyacetylene hot cutting processes, consequently, have been crucially evaluated to optimise the working procedures. Emissions and micronic dusts created in the cutting hall have been analysed through a test campaign, with experimental conditions corresponding to the NPP working parameters. The cut technologies applied to the dismantling (including times and cut rates for tubes and plates of varied thickness and dimension), the production of solid residues and gas emissions (specimen material, invested by the thermal flow, remaining under the solid shape of the dusts and the solid drops collected in the drip/pan, or released in the gaseous state) and the evaluation of the effects on the environment atmosphere are reported in [1-5]. Another research related to cutting operations and also spread of radioactive contamination during the dismantling of a nuclear metal component can be mentioned, referred to E. Fermi NPP (Trino Vercellese, Italy), equipped with a 272 MW_e pressurized water reactor (PWR) and in operation from 1965 to 1987 [6].

The present paper considers different aspects, mainly directed to:

- the analysis of the emissions (how they are composed at the production, how they develop and in which measures they pollute the cut workshop atmosphere or the inhalation by the worker, etc.);
- the physical conditions present at the production (thermal field of the specimen near the cut, space distribution of the temperatures, etc.);
- the composition of the suspended materials and the dimensional entity of the micronic particles in dusts forming the solid portion of the gas suspension present in the cut workshop atmosphere.

The main aim is to plan some simple rules to supervise and interpret the calculation of the quantity of the produced gases, starting from an estimation of the smoke flows released during oxyacetylene and plasma torch cutting processes. From this quantity, it is possible to go back to the portion of emissions collected in a closed environment -subjected to a very restricted hourly exchange by the hall ventilation- and consecutively to the portion of emis-

sions present at the inhalation by the workers performing the cut. The values of these portions are obtained mainly by deductions and guiding hypotheses. They can be verified and calibrated thanks to the mentioned test campaign.

The information acquired by this validation process can be related to comparable operations, by observing some essential conditions. The dust particles conveyed by the smoke captured from the suction mouth of the filtration system have been confined on Teflon filtering supports. All the specimens, submitted to segmentation, have contributed to the experimental activities. At least a support from the gaseous flow upstream of the absolute filter and another downstream were derived. The first one is essential to determine the dimensional composition of the particles existing in either those fines composing the filter bed, or those coarse. An extra examination has been carried out, at least on one filter per specimen and together with the morphological investigation, in order to describe qualitatively the chemical composition of the particles having the most relevant dimensions.

The eventual aerosol in the downstream air of the absolute filter identifies the predominant conditions in the concentration of the dust. It has been verified that the absolute filter really "drains" enough the solid particles until the dimensions prescribed by the technical specification of the filtering system. It is not possible to avoid finding also bigger particles, considering the typical stopping probability of the filtering mass. Another source of such particles, besides, can be derived from the aerosol mixture that gravitates in the plentiful environmental pollution. The deposition of these masses can happen just by simple contact of the filter with the air of the cutting room, which is rich of this suspension.

Some investigations carried out by thermal camera add further information concerning the physical aspects and the regime of intervention on the material. To know the physical conditions, in which the smoke or simply the emissions evolve, is certainly useful, especially in studying the diffusion regimes of the aerosol, the aggregation mechanisms of the sub-micronic particles and the dynamics on such products in concomitance with different phenomena (condensing, etc.). The obtainable

Table 1. Specimens description, cutting procedures and samples

<i>Specimens form/size/position during experimental tests</i>	<i>Cutting procedures and samples</i>
1 Piping spools, 4", Schedule 40S, thickness 7 mm, external diameter 115 mm, placed in horizontal axis position	a) A1 oxyacetylene cutting (3 samples)
2 Piping spools, 10", Schedule 60, thickness 12 mm, external diameter 270 mm, placed in horizontal axis position	a) B1 oxyacetylene cutting (3 samples) b) B2 plasma cutting (3 samples)
3 Piping spools, 6", Schedule 60, thickness 7 mm, external diameter 168 mm, placed in vertical axis position	a) C1 plasma cutting (3 samples)
4 Piping spools, 24"/30", Schedule 40XS/30, thicknesses 20/18 mm, external diameters 610/775 mm, placed in horizontal axis position	a) D1 two spools, oxyacetylene cutting (2 samples for 30" spool and 1 sample for 24") b) D2 two spools, plasma cutting (1 sample for 30" spool and 2 samples for 24" spool)
5 One thin steel plate, thickness 20 mm, one thick steel plate, thickness 40 mm, and two flanges, thickness 22 mm, diameter 626 mm, placed in horizontal position	a) E1 plates, oxyacetylene cutting (2 samples for thin plate, 1 sample for thick plate) b) E2 flanges, plasma cutting (3 samples)
6 Different materials/pieces	a) filtering support not used during the tests (1 sample), also called "white filter" b) paper filter (1 sample) c) personal filter (1 sample) corresponding to the position P1 of Table 2 d) slags produced by oxyacetylene cutting of 1 specimen (1 sample) e) slags produced by cutting a thick plate of 10" pipe, case B1 (1 sample) f) material from the flange, case E1 (1 sample) g) structural material from the 10" pipe, case B1 (1 sample) h) slags produced by cutting a thick plate, case E1 (1 sample)

Table 2. Environmental sampling

<i>Components</i>	<i>Pers. P1⁽¹⁾ (mg/m³)</i>	<i>Env. A1⁽¹⁾ (mg/m³)</i>	<i>Env. A2⁽²⁾ (mg/m³)</i>	<i>Env. A3⁽²⁾ (mg/m³)</i>	<i>Acceptable limit (mg/m³)</i>
Powders	5.600	2.800	4.400	0.100	10.00
Mn	0.023	0.010	0.011	0.001	2.00
Ni	n. d. t.	0.003	0.005	n. d. t.	0.10
Cr (total)	n. d. t.	n. d. t.	n. d. t.	n. d. t.	0.50
Cr VI	n. d. t.	n. d. t.	-	-	0.01
Zn	0.015	0.362	0.469	0.253	10.00
Pb	<u>0.260⁽³⁾</u>	0.059 ⁽³⁾	<u>0.307⁽³⁾</u>	0.003	0.05
Ca	-	-	0.562	1.483	5.00
Cu	-	-	0.067	0.001	1.00
NO _x	n. d. t.	n. d. t.	n. d. t.	n. d. t.	31.00
V. O. S.	n. d. t.	n. d. t.	n. d. t.	n. d. t.	-

Notes

P1 = sampling at level of cutting operator face

A1 = sampling of internal atmospheric air in the first section

A2 = sampling of internal atmospheric air in the second section

A3 = sampling of outside atmospheric air

V. O. S. = volatile organic substances

n.d.t. = not detectable traces

⁽¹⁾ First series of samplings⁽²⁾ Second series of samplings⁽³⁾ Values exceeding the acceptable limits reported in the last column

consideration, however, seem to concern more the technological aspect than the qualification of the emissions.

2. Pollution in the cutting room and at the inhalation by workers

2.1 Conditions consequent to the cutting campaign

2.1.1 Considerations on the measured values in relation with the acceptable limits

The full series of specimens and the number of samples adopted for the cutting tests are reported in Table 1.

The data from Table 2 describe the conditions existing in the cutting room during the various phases of the dismantlement campaign of the specimens.

Table 2 allows advising some considerations related to a certain number of variables. Firstly, the content of the dust and of all the other superior elements in the concentrations detected at the level of the worker (first series of samplings) is higher than that measured in the cutting room. The metallic elements such as Ni and Zn are exceptions: Ni goes from a not detectable level at the inhalation by the personnel to 0.003 mg/Nm³ in the environment, while for Zn the values are 0.015 mg/Nm³ for the personnel and 0.362 mg/Nm³ in the environment. Both values, thus, are under the acceptable limits. For the dusts, the values are 5.60 mg/Nm³ for the personnel and about the half (2.80 mg/Nm³) in the environment, with a limit of 10.00 mg/Nm³. A different situation happens for Pb: the boundary of acceptability at the inhalation by the personnel is exceeded (0.26 mg/Nm³ against the suitable value of 0.05 mg/Nm³). Very low values or absolutely not detectable traces have been assessed for all the remaining elements.

In the second series of samplings, the personnel are not more monitored, but the outside and inside environments are controlled. For the natural outside atmosphere, an extremely lower content of the same elements has been verified, with respect either to the acceptable limits, or to the values measured in the inside environment. A higher concentration has been verified only for Ca, with respect to inside environment, i.e. 1.483 mg/Nm³ in the outside air and 0.562 mg/Nm³ in the cutting room. The values

obtained for the second series of samplings, in general and for all the examined quantities, are superior to those related to the first series, beginning from the dust, which reaches 4.4 mg/Nm³ against the 2.8 mg/Nm³ of the first series. This difference is due also to the greater number of pieces related to the second series. For the first series, the cutting time was 1.5 hours, either with the oxyacetylene, or with the plasma torch. For the second series, the oxyacetylene cutting time was 4.5 h (nine intervals of half hour each). By extrapolating linearly from the first series' data, for the second ones a level of 2.8 mg/Nm³ × 4.5 h/2.8 h = 4.5 mg/Nm³ could be reached. This figure is not far from that really measured, so it is reasonable to admit a direct dependence with the cutting time. The other variables (ventilation of the cutting room, typology of the cutting device, manual operation of the cutting process, physico-mechanical characteristics of the structural material, etc.) remain the same and neglect the influence of technological quantities such as cutting speed versus thickness and shape of the specimen, continuous cut for half hour intervals and hot cutting process typology.

The following aspects of the cutting campaign are also significant:

- the workers operated on specimens of different shape (pipes and plates) but of the same structural material;
- the specimens were placed horizontally, at optimal height from the ground and conveniently with respect to the emissions' capture, that was positioned at appropriate distance from the piece and the worker;
- the cutting operation during the work interval (half hour) was continuous, while the pause between two consecutive intervals varied from few minutes to hours (e.g., the lunch pause between the morning and the afternoon sequences);
- only one worker was operating in the cutting room, thus no other sources (e.g., noise, emissions) were present;
- the environment ventilation capacity (~1.750 m³) corresponds to one exchange per hour and it is maintained constant during the whole day in which the cutting session is carried out, in order to allow the limitless presence of the personnel. Data of local air exchanging system are depending on the design of the power station. We have to respect these data, taking into

account that our research is performed in white zones of the power plant itself.

These specimen positions are not always usual during dismantlement works of a plant. There, the cut is carried out where necessary and not in the better conditions of emissions capture. The pessimistic values of Tab. 2, thus, are not only due to the long durations of every cut session (from 3 hours to 4.5 h), with considerable cutting speed and consequent high quantity of material involved in the numerous cuts. The pollution may not depend only from the cuts' duration, especially if the specimen external surface were treated with anti-oxidising painting. Reasonable values, moreover, have been found related to all the substances -including nitrogen oxides- for those compounds, present in the emissions produced by some cuts and obtained from the upstream flows of the absolute filter, for which a particularly significant production rate has been verified.

2.1.2 Measures to limit Pb excess

The Pb concentration in the dust (due to the painted pieces), as above mentioned, is over the acceptable limit of 0.05 mg/Nm³. In fact, it reached the following figures: 0.26 mg/Nm³ at the inhalation level for the worker; 0.059 mg/Nm³ in the environment (first series of samplings); 0.307 mg/Nm³ in the air of the cutting room (second series of samplings). The overcoming is not irrelevant, since it is 5.2 times higher for the inhalation, 1.2 times for the environment (first series of samplings) and 6.14 times for the second series of samplings. These values are still superior also adopting the limit of 0.15 mg/Nm³ fixed by the Italian Decree of Apr. 9, 2008 Annex XXXVIII, transposed in Tab. 2. The values exceeding this limit have been underlined even if they are referred to a shorter working time (1.5 hours in comparison with 8 hours reported in Italian Decree).

Once ascertained -by analysing the dusts- the overcoming of the fixed limits, if it is impossible to move the specimen in a suitable environment, could be appropriate to put into effect the following preventive measures:

- to increase sensitively the local ventilation on the specimen (including a filtration if the cut environment is isolated towards outside), in order to dilute as more as possible the emissions in the air mixture;

- to displace the worker from the specimen under cut or change the cutting procedure (from manual to automatic) or shield the worker (total protection) because it is impossible to isolate or shield the source;
- to increase the local capture on the cut point;
- to reduce the cutting times per day, with reference to spool rich of the element causing the non-compliance of the limits.

The last measure is not very suitable. Facing overcoming of 5 or 6 times of the acceptable quantity, in fact, the cut's duration -collected in a full day of work- should be properly reduced to 1.3-1.6 hours (instead of the standard 8 hours) and this is not much productive, neither very useful or practical.

2.1.3 Effects of hot cutting processes on the cut workshop environment

The residual produced attest that the operating personnel have been properly qualified before starting the cutting campaign. Many tests, in fact, are normally expected and requested in view of respecting the strict limits on the activated elements in all the steels going out from the dismantling area. The cut surfaces of the pipes ring sections are substantially parallel between them and the engraving formed by the inner cone is enough linear also with reference to the oxyacetylene cutting process.

The high temperatures produced by the plasma torch work have heavy influences on the external surface treatments and the inner contaminations. The depots and the surface protective films submitted to these thermal conditions generate volatile substances, which are in supplement to the gaseous emissions, created by the melting/volatilization of the structural material and freed during the cut.

The environmental pollution conditions in the ~1.750 m³ cutting room were really intolerable during the campaign by plasma. It was needed to open completely the large main entrance, as well as to keep strongly active the ventilation. The smell of burnt and oxidized iron and the rather dense gas suspension, moreover, reduced the visibility. They diffused rapidly either in the cutting room or, crosswise the stair of access to the two upper floors, to the whole building. Nothing similar happened during the cutting processes by oxyacetylene: air clear

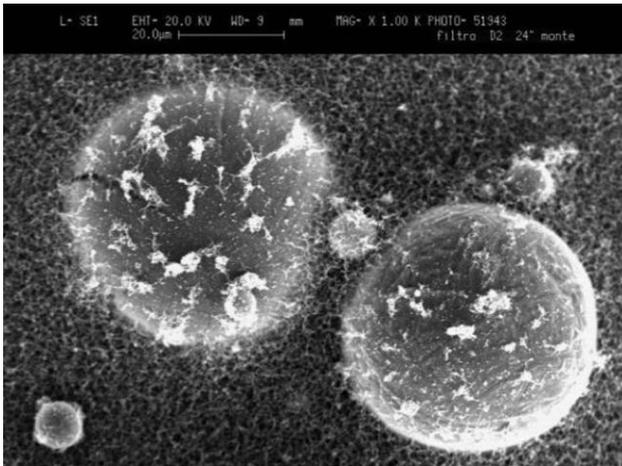


Figure 1. Single particles on a carpet of fine particles. 24" spool specimen, D2 test, upstream.

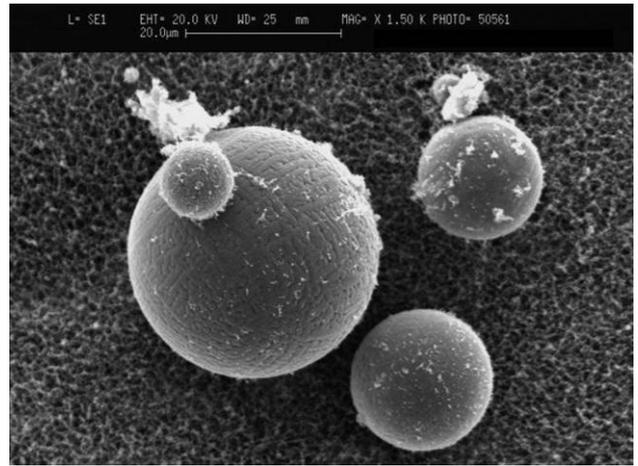


Figure 2. Single particles on a carpet of fine particles. 4" pipe specimen, A1 test, upstream.

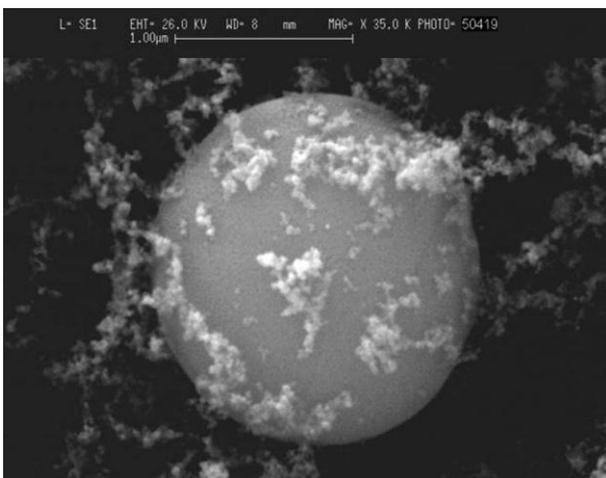


Figure 3. Single particle captured by the filtering support. 10" pipe specimen, B2 test, upstream.



Figure 4. Fragment of a carpet of ultra fine particles captured by the filtering support. 10" pipe specimen, B2 test, upstream.

ness and smell were slightly changed, proceeding with the cuts.

The measurements temperature was not superior of 15 degrees with respect to the design temperature. Clearly, it is necessary to take into account of where it is measured the temperature: for example, if near the apertures of suction, or in other zones.

To describe and evaluate the mass of the secondary products and the consequent influences of the gas suspension on the environment, the effect of these conditions on the comfort and on the workers' reactions should be also considered.

It has been emphasized that a same piece, submitted to both cutting processes, produces - also visually - a more significant and more directly detectable environmental pollution by using

plasma torch. The same consideration have already arisen considering the dust quantities created by the two cutting processes and clearly detected by the filtering supports arranged for these evaluations. The composition of the aeriform parts that gravitate in the cutting room environment, consequently, should be studied: in fact, it is not feasible to retain that only the iron (or other heavy elements) oxides and the aerosols -even if in sub-micronic particles- or eventually the ozone, have been able to diffuse and saturate in the cutting room and in the upper floors of the building, in which the cutting campaign has been carried out.

A chemical analysis of the aeriforms present in the room environment during the cutting processes is essential, since knowledge of their spectra and compounds can supply useful information to determine the safety measures. The procedure to assess the quantity of the pro-

duced fumes should be also submitted to a stricter experimental evaluation, in order to facilitate the determination of the hazard related to these emissions. Figs. 1 and 2 show single particles on a carpet of fine particles.

Fig. 3 shows a single particle, while Fig. 4 shows a fragment of a carpet of ultra-fine particles, all captured by the filtering support during a plasma torch cutting process.

2.2 Procedure to evaluate the pollution level

2.2.1 Calculation of the pollution concentrations

The first series of samplings has been particularly significant, since it allowed evaluating the environmental (for the effects on the general comfort) and human (for the effects on the inhalation) pollution. The obtained data have been used to interpret and assess also the future regimes of pollution.

It would be appropriate to carry on the calculation of the pollution level not only in the environment, but also at the worker's suction point. Then these data have to be compared with the values obtained during the first session. To make that, it is timely to express some hypothesis, useful to predict reasonably the pollution for the successive sessions of the cutting campaign. The sense is to offer an appropriate procedure to determine the pollution in other different fields.

A question immediately arisen concerns the possibility of extrapolating the present considerations to real cases, which are different from those linked with this cutting campaign. Some difficulties and typicalities can occur. They could change substantially the logic direction practised (layout of the place in which the cutting tests are carried out, vorticity and local currents, technological processes, materials, work durations, procedure of suction at the cut point and at the worker, position assumed by the worker, environmental ventilation, etc.). These parameters would not influence greatly the effects on inhalation, if the worker operates downstream of the emissions flow, freed from the hot cut.

In a first hypothesis, the fumes concentration detected in the chimney is supposed to be the same of these in the suction point and, conse-

quently, in the vapours overhanging the cutting point. By knowing the capacity of the emissions that are not conveyed in the mouth of the sucking tube, it is possible to calculate the capacity in weight, passing in the vicinity of the worker's mouth during the oxyacetylene cutting process. The same calculation is repeated for the plasma and both capacities are summed. The result, then, is divided for the sum of the volumetric capacities of the fumes emitted by both processes, assuming that: the contribution of the same fumes mixing in the cut environment influences also the second cut. The local suction by the ventilation system does not modify sensitively the diffusion and the presence of the fumes. The penetration of the fumes in the environment cannot be represented, admitting that the produced gasses are homogeneously and instantaneously distributed in the whole volume of the workshop. That would be valid for the application of the partial pressures principle, but not for the formal procedures of introduction and diffusion of fumes and dusts in the workshop. To fill uniformly the workshop by such polluting mixture requires a certain time, since the processes involved in this phenomenon are associated to different mechanisms (aerosol diffusion/condensing, thermal exchange between gas masses with different density and composition, upward tendency and successive fallen of warm gas columns, turbulence and suction of the blasts from the open main entrance towards the outside environment, etc.).

In a second hypothesis, the fumes diffusion is supposed to be enough slow, so they are confined within narrow volumetric limits. Consequently, their quantity changes depending on the volumetric capacities in the chimney and in the environment around the cutting point. The fumes concentration, thus, is a function of their capacity. Since the capacity of the fumes conveyed to the filter is double of that diffused in the environment outside the flexible pipe - which connects the cap with both measurement chimney and absolute filter-, the distribution of the concentrations will be similar. In the environment outside the sucking proboscis, therefore, the pollution concentration will be the half of that measured in the chimney. These quantities are calculated for the emissions produced by oxyacetylene and plasma torch and then they are summed. The value obtained is put in correlation with the concentration directly measured by a sensor placed on the chest of the worker.

The relation between the two values represents the dilution of the fumes when they are inhaled by the worker. The dust concentration within the chimney would be 7.4 mg/Nm^3 for the oxy-acetylene cut and 185 mg/Nm^3 for the plasma cut; their half. Thus, is in the fumes dispersed in the environment.

In a third hypothesis, the concentrations of the dusts detected and measured in the chimney for both cutting procedures are equal for the dusts contained in the fumes dispersed in the environment. Their sum would permit calculating the resulting condition. This situation could make to estimate the highest value of the dust concentration at the inhalation by the worker involved in the cutting process.

Not all the workshop zones (especially, if they are far from vorticity and fumes generation) are able to be equally rich of pollutants and as much sensitive to the presence of the dusts during the cutting process. The confirmation is either in the indications from the environmental sensor, which is placed some meter far from the cutting point, or from the visual observation of the movement of the pollutants' "foggy" masses. The value of the local concentration of the dusts is a lot higher than the uniform distribution obtainable by dividing the produced dusts quantity for the volume of the workshop. Fig. 5 shows spherical bodies of $\sim 2.5 \mu\text{m}$ immersed in a carpet of very fine particles.

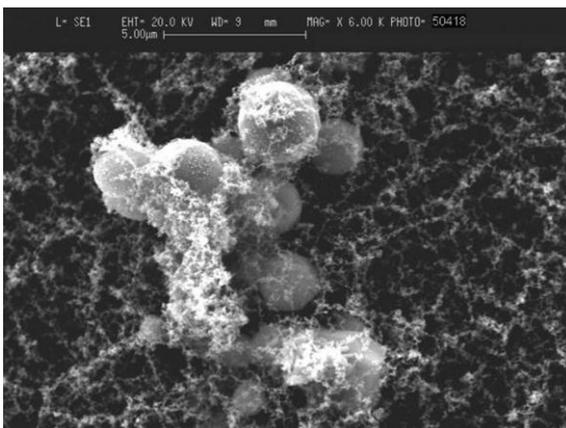


Figure 5. Spherical bodies of $\sim 2.5 \mu\text{m}$ immersed in a carpet of very fine particles. 10" pipe specimen, B2 test, upstream.

2.2.2 Pollution values at the inhalation

The results attainable by estimating the quantity of aeriforms emitted during the cutting tests could appear very imprecise. The process is

complicated by various factors related to the production of the emissions (e.g., the thermodynamic conditions of the room in which the emissions are produced, the dispersal of the fumes, the physico-chemical features of the vapours contacting the air, the typology of the produced aeriforms in connection to the original materials and to the adopted technological processes).

The quantitative determination of the gaseous releases results complicated by the most important need to reach the greatest efficiency in the fumes collection. It is essential, in fact, to capture the emitted fumes in the greater possible measure, if not feasible for the whole quantity. It is necessary, therefore, to activate the utmost the capacity of the filtering system, the sucked gas mass and the convey of the sucked quantities to the filtering system, which is capable to arrest the dusts till a suitable dimensional level (HEPA absolute filter). It is crucial, for the collection efficiency, to determine all the involved quantities and particularly the subdivision of the collected fumes capacity with respect to that not collected.

To assess the volume of the produced fumes is not easy also due to the numerous variables involved (e.g., thickness/shape/material of the specimen, ability of the worker, technological parameters specifically related to the cutting device, time/track of the cut). Nevertheless, this assessment is essential. It is necessary, besides, to take into account also the intervention of the filter (capacity, efficiency vs. typology and physical data of the fluid, etc.), to have an idea of how much fumes remain in the environment.

In the sucked air and fumes flow, it is possible to determine with precision the concentrations of metallic elements, dust and substances, by knowing the capacity of the gas passing in the measurement chimney. This information can be valid as a reference that should be supplemented by an approximate relation between the produced fumes, those collected and those dispersed in the environment.

3. Calculated values of pollution

3.1 Concentrations of pollution assessed during the first series of sampling

Table 3 contains a list of the various samplings. In the first series of samplings, the 4" piping

Table 3. List of the various samplings carried out in the experimental campaign

<i>Specimen type</i>	<i>Test code</i>	<i>Oxyacetylene</i>	<i>Plasma torch</i>	<i>Number of cuts without sampling</i>
4" pipe	A1 ⁽¹⁾	3	-	1
10" pipe	B2 ⁽¹⁾	-	3	-
10" pipe	B1 ⁽²⁾	3	-	1
6" pipe	C1 ⁽³⁾	-	3	-
24" spool	D1 ⁽²⁾	1	-	-
24" spool	D2 ⁽³⁾	-	2	-
30" spool	D1 ⁽²⁾	2	-	-
30" spool	D2 ⁽³⁾	-	1	-
Flanges	E2 ⁽³⁾	-	3	-
Thin plate	E1 ⁽²⁾	2	-	-
Thick plate	E1 ⁽²⁾	1	-	1

Notes

The extra cuts - indicated in the last column - are not related to samplings, since they have been planned to define the cut quantity. For the specimens' description, see Table 1.

⁽¹⁾ Test carried out during the first series of samplings. ⁽²⁾ Test carried out during the second series of samplings. ⁽³⁾ Test carried out during the third series of samplings.

spool has been cut by oxyacetylene, then the 10" spool (coated on the outside wall by protective paints) has been cut by plasma torch.

3.1.1 Oxyacetylene cut of 4" piping

The oxyacetylene cutting tests of the 4" piping have involved 90 work minutes and 6,950 g of material, of which -according to the balance between melted material, that remained joined to the specimen and the dust collected in the drip-pan- ~3,385 g have been probably volatilized. The total capacity of the emissions, appraised on a presumptive basis by means of rational evaluation, supposing an average of the molecular weights and taking into account the molar volume, is 1,200 l/h. In fact, since the considered material is mainly iron and the atomic weight Ar of the ferritic alloy corresponds to the 80% of the Fe56 element, it is reasonable to retain that:

$$A_r = 0.8 \times 56 \text{ g} / \text{gmole} = 45 \text{ g} / \text{gmole} \quad (1)$$

To determine the volume of volatilised material per hour, the value of the atomic weight reported in (1) is assumed, together with the following value of the molar volume V_m at 20°C (as per ideal gas law $pV=nRT$ with $n=1$):

$$\begin{aligned} V_m &= 22.4 \text{ l} / \text{gmole} \times 293^\circ \text{K} / 273^\circ \text{K} \\ &= 24.04 \text{ l} / \text{gmole} \end{aligned} \quad (2)$$

By admitting that the volatilised elements are comparable to ideal gasses, the following relation is obtained:

$$\begin{aligned} &3,385 \text{ g} / (1.5 \text{ h} \times 45 \text{ g} / \text{gmole}) = \\ &= 2,256 \text{ g} / \text{h} / 45 \text{ g} / \text{gmole} = 50.13 \text{ gmole} / \text{h} \\ &50.13 \text{ gmole} / \text{h} \times 24 \text{ l} / \text{gmole} = 1,203 \text{ l} / \text{h} = \\ &= 1.203 \text{ m}^3 / \text{h} \approx 1,200 \text{ l} / \text{h} \\ &1,200 \text{ l} / \text{h} / 60 \text{ min} / \text{h} = 20 \text{ l} / \text{min} = 0.02 \text{ m}^3 / \text{min} \quad (3) \end{aligned}$$

The emissions' collection, ensured by the suction carried out through the cap, removes an average capacity of 800 m³/h of mixture, which would be widely in excess with respect to that of the fumes (1.2 m³/h) and should be sufficient to suck it completely. Nevertheless, one should take into account that, really, the sub-micronic aerosols are submitted to diffusion and condensation processes, further than to turbulences from thermal motions. It is necessary, therefore, to verify if the emissions' collection includes the entire cut fumes (or not rather much air) within its virtual cone. By assuming that the cross sectional area of the cap is ~0.05 m² (equal to a circle having a diameter of 0.25 m), the suction speed v_s would result:

$$v_s = 800 \text{ m}^3 / \text{h} / (3,600 \text{ s} / \text{h} \times 0.05 \text{ m}^2) = 4.4 \text{ m} / \text{s} \quad (4)$$

By projecting the suction virtual cone to a distance of 0.4-0.5 m, the cross sectional area would correspond to ~0.5 m², i.e. ten times larger. The speed of the gaseous fluids flows would have been reduced to a tenth one of the previous value, thus below the value (0.5 m/s) necessary to have still a real suction of the fumes. The quantity of the collected emissions, then, if the cap is not located on the vertical of the cut, but on a sloping straight line, would be

further reduced. Besides, due to technological requirements, the cap cannot be positioned to a distance lower than 0.3-0.4 m from the cutting point.

On the basis of superimposing the suction cone and that of the fumes produced during the cut, it is possible to formulate indicatively the precautionary hypothesis that a third part of the volatilised material is not conveyed in the cap that provides to suck air-fumes mixture and to send it to the absolute filter.

The measured dusts capacity, present in the fumes and air mixture directed to the chimney, is 116.5 mg/min, corresponding to an hourly capacity of 6.99 g/h.

By adding a half of the same value - having hypothesized that a third of the fumes total capacity escapes from the influence of the cap -, it is possible to obtain the dusts capacity in the fumes that are freed from the volatilization of the pipe wall constitutive material. This value is:

$$6.99 \text{ g/h} + 3.5 \text{ g/h} \approx 10.5 \text{ g/h} \quad (5)$$

It would remain, however, a circulating emissions' capacity of 3.5 g/h. By assuming that these emissions are diffused instantaneously in the whole room volume, the ventilation capacity, which is based on a single hourly exchange, would ensure a depollution almost total. The dusts production, in fact, would proceed with a speed equal to that of the outwards disposal. This positive configuration, unfortunately, is only theoretical. In the reality, it will be necessary a lot more time to obtain the purpose.

To assess the concentration of dust inhaled by the worker - who carries out the cut operations in a standing position -, one should take into account that: the point of inhalation by the worker is placed at ~1 m from the cut table; it is probable that the dilution is different from that existing in the capacity collected by the cap. By admitting that a third of the fumes capacity is deviated towards the cut environment, the corresponding dusts capacity (3.5 g/h), which is appraised on the base of that existing in the chimney, produces in the sole fumes the following concentration:

$$\frac{3.5 \text{ g/h}}{0.400 \text{ m}^3/\text{h}} = 8.75 \text{ g/m}^3 \quad (6)$$

The breathable concentration would be equal to $f' \times 8.75 \text{ g/m}^3$, where f' is a dimensionless quantity, physically corresponding to the real dusts concentration at the inhalation vs. that found in the fumes capacity, produced by cut and not sucked by the cap. In this case, f' means a reductive coefficient of the capacity in weight of the dusts in the fumes released in the environment, due to the mixing. The breathable dusts, considering for instance a third of the fumes not sucked by the cap, could correspond to:

$$(10.5 \text{ g/h} \times 1.5 \text{ h}) / 6.956 \text{ g} = 0.22\% \quad (7)$$

of the involved material and to:

$$(10.5 \text{ g/h} \times 1.5 \text{ h}) / 3.385 \text{ g} = 0.46\% \quad (8)$$

of that volatilised.

The imposed condition, in the case of the oxyacetylene cut, could be too much pejorative. It would be more appropriate, therefore, to reduce the fraction of the fumes not sucked by the cap, from the hypothesized value of 33% to a ~20% for the oxyacetylene cut, as well as to enhance the mentioned fraction to ~40% for the plasma cut. The diffusion of the cut vapours, by following this indication, would become really high.

3.1.2 Plasma cut of 10" piping

In the case of plasma cut of 10" piping, the melted material amounts to 5,697 g and that volatilized to 3,138 g. By using the procedure cited in par. 3.1.1, the assessed capacity of the emissions produced during the cutting process and the consequent concentration of the dusts in the fumes is 69 g/m^3 . By repeating the previous considerations, the fumes capacity would result:

$$\begin{aligned} & 3,138 \text{ g} / (1.5 \text{ h} \times 45 \text{ g/gmole}) = \\ & = 2,092 \text{ g/h} / 45 \text{ g/gmole} = 46.5 \text{ gmole/h} \\ & 46.5 \text{ gmole/h} \times 24 \text{ l/gmole} = \\ & = 1,116 \text{ l/h} = 1.116 \text{ m}^3/\text{h} \approx 20 \text{ l/min} \end{aligned} \quad (9)$$

The dusts capacity - if that of the dusts existing in the mixture going through the measurement pipe is 920 mg/min - would result:

$$\begin{aligned} & 920 \text{ mg/min} \times 60 \text{ min/h} = 55,200 \text{ mg/h} = \\ & = 55.2 \text{ g/h} \end{aligned} \quad (10)$$

By applying the same criterion as in par. 3.1.1 and admitting that a third part of the fumes ca-

capacity is deviated towards the environment, the corresponding dusts quantity would be the half of the capacity previously reported, i.e. 27.6 g/h, equal to a concentration of:

$$27.6 \text{ g/h} / 0.400 \text{ m}^3 / \text{h} = 69 \text{ g/m}^3 \quad (11)$$

in the sole fumes. If the conditions indicated in the previous case are confirmed, the concentration at the inhalation would be equal to f'' 69 g/m³. The reductive factor, in principle, could be set different from the previous case, since it is not possible to know if the conditions of the fumes behaviour during the plasma cut are different from those during the oxyacetylene.

3.1.3 Concentration at the inhalation

During the first series of sampling, the sensor placed in correspondence of the operator should have pointed out a concentration, which likely takes into account that, in the air, a part of the contribution of dust remains from the previous cut with respect to that carried out of the 10" pipe. It is possible to believe that the dusts concentration – if we consider the first hypothesis mentioned in Par. 2.2.1 - is determinable by using the following relation (in which $f' = f'' = f$):

$$\begin{aligned} f(7.9 \text{ mg/Nm}^3 \times 0.4 \text{ m}^3/\text{h} + 185 \text{ mg/Nm}^3 \times \\ \times 0.4 \text{ m}^3/\text{h}) / (0.4 \text{ m}^3/\text{h} + 0.4 \text{ m}^3/\text{h}) = 5.6 \text{ mg/Nm}^3 \\ f \times 192.9 \text{ mg/h} / 2 \text{ m}^3/\text{h} = 5.6 \text{ mg/Nm}^3 \\ f 96.45 \text{ mg/Nm}^3 = 5.6 \text{ mg/Nm}^3 \end{aligned} \quad (12)$$

from which it is obtained $f = 0.058$.

By relating the measured concentration (5.6 mg/m³) to that calculated, the so called “mixing reference indicator” is determined, which is the opposite of the singular reduction factor f :

$$1/f = 96.45 / 5.6 = 17.22 \quad (13)$$

This is physically interpretable in the sense that ~17 parts of air, with respect to one part of cut fumes, contribute to form the mixture.

Such number could be reduced or increased, depending on the hot cutting procedure adopted and if the cuts are numerically varied in every cut session. The quantity $1/f$, thus, indicates the correspondence with the dilution. The higher is its entity, consequently, the more sensitive will be the mixing and the lower will be the concen-

tration at the inhalation. Taking into account the second hypothesis mentioned in Par. 2.2.1, the relation would result:

$$\begin{aligned} f(7.9 \text{ mg/Nm}^3 \times 0.5 + 185 \text{ mg/Nm}^3 \times 0.5) = \\ = 5.6 \text{ mg/Nm}^3 \\ f 96.45 \text{ mg/Nm}^3 = 5.6 \text{ mg/Nm}^3 \end{aligned} \quad (14)$$

with $f = 0.058$, corresponding to a dilution of ~17 times.

Finally, taking into account the third hypothesis mentioned in Par. 2.2.1, the relation would result:

$$\begin{aligned} f(7.9 \text{ mg/Nm}^3 + 185 \text{ mg/Nm}^3) = 192.9 \text{ mg/Nm}^3 \\ f 192.9 \text{ mg/Nm}^3 = 5.6 \text{ mg/Nm}^3 \end{aligned} \quad (15)$$

with $f = 0.029$, corresponding to a dilution of ~34 times, i.e. the double of the previous value.

3.1.4 Consideration on the concentrations at the inhalation and in the environment after the first session of samplings

The consideration of the previous paragraphs helped appraising the dilution between emissions and air during the inhalation, especially when more cuts are carried out in the same session. If a series of cuts of a same type is carried out, the assessment of the concentration by using the simple indicator number can lead to excessive estimations, since the relation between the volumetric capacity of that cut and the sum of the analogous capacities of the other consequent cuts is missing. It is essential, therefore, to appraise the indicator $1/f$ only through a careful examination of the polluting characteristics of that cut, in order to evaluate correctly the phenomenon.

Concerning the mixing, it is necessary to express some suggestions for the use of the result, in order to consent a correct interpretation of $1/f$ and a consequent appropriate use of the same indicator.

In this condition, decreasing values such as 15, 10, 5, etc., can be justified. The coefficient's increase, instead, leads to a decrease of concentration. Due to reasons opposite to those just indicated, higher values such as 18, 20, etc. could be advised, especially for single cuts, in optimal sampling conditions during the cut and with suction capacities particularly efficient to remove the emissions.

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The pollution rate should be raised, by decreasing $1/f$, due to various reasons, e.g.:

- increasing times of the cut activity, also taking into account that, in the first series of sampling, the cutting operations were continuous during periods of half hour each, with short intervals;
- adoption of cutting technologies, such as plasma torch, involving greater emissions;
- increasing of the fumes capacity due to an unsuitable position of the suction cap or to a scarce efficiency of the local suction system, etc.

A decrease of concentration like that just discussed does not seem to be excessive. The gaseous mass present in the environment is formed by air and emissions, which are freed by the melting of structural material due to the contribution of the thermal flow during the cut. To preserve the breathing, it is desirable that the mixture, inhaled by the worker, is conveniently formed by n parts of air and only one part of fumes produced by the cut. The value of the relation between the two fractions could be also reasonably high. On the other hand, the calculation schemes considered in the previous paragraph have been chosen between those more obvious, so in order to preserve a direct and immediate physical correspondence.

To evaluate the environmental concentration is more difficult, since it is necessary to create a model sufficiently simple but able to appraise the complex concomitant or the more significant phenomena involved. The model should be capable to estimate:

- the fumes diffusion in the environment;
- the mixture of these fumes with the aeriforms returned from the filtering system;
- the mixture subtraction due to the environmental ventilation;
- some of the physical processes influencing this mixture, vs. time (e.g., environmental thermal flows, variation of the physical param-

eters of the air in the environment, local activation of the diffusion motions, conditions of the pollution due to the fumes, physical characteristics of the fumes related to the cut process, different fumes concentration at the beginning and during the different cuts, position of the worker).

The relation between the concentration at the inhalation and that environmental, initially, can be evaluated. The local concentration, during the first series of sampling, was measured in a place within the workshop -some meters distant from the cut point- where fixed sampling equipment was placed. This concentration is 2.8 mg/Nm^3 and the above mentioned relation corresponds to:

$$f_a = 2.8 \text{ mg/Nm}^3 / 5.6 \text{ mg/Nm}^3 = 0.5 \quad (16)$$

In other words, the effect of the various interventions on the gaseous mass of the environment does lower the concentration - estimated at the inhalation point - to about the half.

3.2 Concentrations of pollution assessed during the second and the third series of samplings

3.2.1 Concentrations assessed at the inhalation and in the environment during the second series of samplings

In the second series of samplings, the external surface of some specimens submitted to oxyacetylene cutting process resulted coated with rust-prevented paint, while the inner surface had been submitted to the contact with the process fluids. To rightly estimate the value of the indicator $1/f$, this double "contamination" should be taken into account, since more significant emissions in quantity/quality could be produced with respect to those obtainable by cutting virgin material. Only one case of this type happened, in the first series of samplings, in which the 4" pipe had been naturally oxidized by air exposure.

Table 4 reports, as sequenced, the specimens cut by oxyacetylene in the second series of samplings. Besides the code of the test, the number of the samplings is reported, which is useful to assess the full duration of the cutting process (every period lasts 30 minutes, during which the cutting process is almost continuous, having alternated some breaks necessary, e.g.,

to move the piece or to re-ignite the flame for a new segmentation).

The sixth column reports the product of the numbers listed in the two previous columns. In the seventh column, every value of the previous column is divided for the sum of the volumetric capacities reported the fourth column. In the last line, some values of the $1/f$ coefficient are indicated:

$$\begin{aligned} 1/f &= 45.35 / 5.6 = 8.09 \\ 1/f &= 45.35 / (4.4 \times 2) = 5.15 \end{aligned} \quad (17)$$

The values of the penultimate line of Tab. 4 allow obtaining the concentration at the inhalation referred to the three solutions vs. the $1/f$ indicator, as follows:

$$\begin{aligned} 45,35 / (1/f) \\ 50,59 / (1/f) \\ 100,9 / (1/f) \end{aligned} \quad (18)$$

in order to obtain the same concentration at the inhalation of the 1st series of samplings and a double concentration with respect to that environmental (cited as “Env. A2” in Tab. 2).

By using the same value found for the first session (i.e., 17) with the first solution, which is that of reference, a concentration of 2.66 mg/Nm³ would be obtained against the 4.4 mg/Nm³ really measured. This value is rather debatable, due, at least, to two considerations. Firstly, the cuts duration has prolonged for four and half hours on the theoretical eight work hours beside the three hours of the first session. Secondly, all the specimens were submitted to the plant service, thus they are contaminated. In the introductory cut session, instead, the first series of cuts was carried out on naturally oxidized material and, even if followed by plasma cut of 10” pipe, the emissions during half of the session were much reduced.

Some consideration related to the $1/f$ indicator should be taken into account, which describe the features of the cutting process (e.g., duration and typology), especially when this indicator is used without the support of any experimental confirmation. Table 5 facilitates these considerations, even though we retain that, in a first hypothesis, this indicator can be assumed equal to 10.

The measured value of the environmental pollution was 4.4 mg/Nm³. An allowable concentration of 8.8 mg/Nm³ would be obtained at the level of the worker’s breathing point, if the relation between this concentration and that at the inhalation - already estimated and equal to 0.5 - is valid. This figure -underlined in Tab. 4- seems to be realistic, due to the explanations described in the previous paragraph. The indicator’s value of ~5 results so logical, being based on rational evaluations and measured data. Consequently, it assumes a character of indisputable and reasonable orientation. This value, besides, is aligned with the greater duration of the cuts (4.5 hours in this phase of the campaign, with respect to 3 hours of the first series of samplings). The result for this relation is:

$$5.6 \text{ mg/Nm}^3 \times 4.5 \text{ h} / 3 \text{ h} = 8.4 \text{ mg/Nm}^3 \quad (19)$$

This value is much near to that just found. The result of the evaluations is positive also with respect to the first series of samplings, i.e. the concentration at the worker’s level cannot be lower to that of the first series of samplings, but it has to be necessarily superior.

A further confirmation concerns the achieved value of the environmental pollution, which is higher than in the first series of samplings, passing from 2.8 mg/Nm³ to 4.4 mg/Nm³ with an increase very close to the ratio of the cut’s durations, as already pointed out:

$$2.8 \text{ mg/Nm}^3 \times 4.5 \text{ h} / 3 \text{ h} = 4.2 \text{ mg/Nm}^3 \quad (20)$$

This result is not very different with respect to that measured (4.4 mg/Nm³), as expected.

3.2.2 Concentrations assessed at the inhalation and in the environment during the third series of samplings

In the third series of samplings, some specimens have been submitted to plasma cut (see Table 3). The concentration at the inhalation by the worker carrying out the cut, in this case, is remarkably higher with respect to the oxyacetylene cut. The numerical values obtained seem not to emphasize adequately how much has been verified during the third series of samplings..

The large main entrance of the workshop was kept open during these cutting operations; ne-

Table 4. Characteristics of the oxyacetylene campaign (2nd series of samplings)

<i>Specimen/test code/samplings</i>	<i>2°</i>	<i>3°</i>	<i>4°</i>	<i>5°</i>	<i>6°</i>	<i>7°</i>	<i>8°</i>	<i>9°</i>
10" pipe/B1/3	2,916	1,944	0.346	28.50	9.861	3.41	14.25	28.50
24" spool/D1/1	1,696	2,866	0.955	35.00	63.42	19.55	17.50	35.00
30" spool/D1/2	2,603							
Thin plate/E1/2	5,702	5,826	1.942	37.40	72.63	22.39	18.84	37.40
Thick plate/E1/1	3,038							
Total			3.243			45.35	50.59	100.90
<i>I/f</i> index						8.1-5.1	9-5.8	18-11.5

Legenda:
 2° = Material volatilized in the cut (g); 3° = Dusts capacity in the chimney (g/h); 4° = Fumes volumetric capacity (m³/h); 5° = Dusts concentration in the chimney (mg/Nm³); 6° = Dust capacity in the fumes (mg/h); 7° = Concentration at the inhalation, 1st solution (mg/Nm³); 8° = Concentration at the inhalation, 2nd solution (mg/Nm³); 9° = Concentration at the inhalation, 3rd solution (mg/Nm³)

Table 5. Values of the concentration at the inhalation vs. 1/f indicator

<i>I/f</i>	<i>Concentration at the inhalation 1st solution (mg/Nm³)</i>	<i>Concentration at the inhalation 2nd solution (mg/Nm³)</i>	<i>Concentration at the inhalation 3rd solution (mg/Nm³)</i>
30.0	1.51	1.68	3.37
20.0	2.26	2.52	5.06
18.0	2.52	2.81	5.62
17.0	2.66	2.97	5.94
11.5	3.94	4.39	8.78
10.0	4.53	5.05	10.01
9.0	5.04	5.62	11.24
8.1	5.60	6.24	12.48
5.8	7.81	8.72	17.44
5.1	8.89	9.91	19.82
4.0	1.33	12.64	25.29
2.0	22.66	25.28	50.58

Table 6. Characteristics of the plasma cut campaign (third series of samplings)

<i>Specimen/test code/samplings</i>	<i>2nd</i>	<i>3rd</i>	<i>4th</i>	<i>5th</i>	<i>6th</i>	<i>7th</i>	<i>8th</i>	<i>9th</i>
24" spool /D2/2	2,725	2,547	1.360	186.40	253.50	88.60	93.20	186.4
30" Spool /D2/1	1,096							
Flanges/E2/3	11,291	166.30	1.249	207.90	259.70	90.76	103.95	207.9
6" pipe/C1/3	2,374	148.00	0.262	185.00	48.47	19.94	92.50	185.0
Total			2.861		561.67	199.30	289.65	579.3

Legenda:
 2nd = Material volatilized in the cut (g); 3rd = Dusts capacity in the chimney (g/h); 4th = Fumes volumetric capacity (m³/h); 5th = Dusts concentration in the chimney (mg/Nm³); 6th = Dust capacity in the fumes (mg/h); 7th = Concentration at the inhalation, 1st solution (mg/Nm³); 8th = Concentration at the inhalation, 2nd solution (mg/Nm³); 9th = Concentration at the inhalation, 3rd solution (mg/Nm³)

vertheless, it was not enough to limit the environmental pollution within acceptable levels.

Assuming $I/f = 10$ and with reference to the first hypothesis of par. 2.2.1, the concentration at the inhalation would be 19.9 mg/Nm³ and the corresponding environmental concentration 8.85 mg/Nm³. This postulation, however, seems to err widely by default. It is inconceivable, in fact, that the I/f indicator can be superior to that related to the oxyacetylene session,

for which $I/f = \sim 5$. Therefore, if this value is assumed also in this case, no substantial objections would arise, apparently.

Table 6 reports, similarly to Table 4, the specimens cut by plasma torch in the third series of samplings.

A reasonable value of the pollution at the level of the worker's breathing point, consequently, should be at least:

$$199.3 \text{ mg/Nm}^3 / 5 \approx 40 \text{ mg/Nm}^3 \quad (21)$$

i.e., an undeniably excessive value. The environmental concentration could reach the following value:

$$40 \text{ mg/Nm}^3 \times 0.5 = 20 \text{ mg/Nm}^3 \quad (22)$$

The gap with respect to the values assessed for the local pollution during the oxyacetylene processes, does not seem to be inconceivable, even if it is worrying. In the case of plasma torch, in fact, the increase can be 5 or 6 times higher with respect to the corresponding data related to the oxyacetylene.

4. Final considerations

4.1. Conclusive remarks

The evaluations reported may be considered reliable and acceptable, since they have been developed through a rational process and experimentally verified. It is noticeable that the evaluative principle, based on the first hypothesis of par. 2.2.1, is definitively preferred with respect to the others, which show also higher values of pollution.

NPP decommissioning should be, on the whole: *secure* for the operating personnel and for the material involved; *precise*, in the sense of leading with certainty the activities in the most appropriate approach without the need of expecting further actions to complete the work; *economically balanced*, in order to produce residuals to be disposed or contained in the possible minor quantity; *rapid*, to reach the purpose in suitably limited times and with easily determined duration.

An accurate examination should concern the activities involved during the cuts and, above all, the measures, which could be appraised with the perspective of an enhancement or a planning of the same operations. The following considerations can be taken into account:

- the effect of the ventilation in the cutting room - considering one air exchange per hour - is minimal, especially when the cut proceeds on very oxidized and/or painted pieces;
- the suction through a unique mouth is partial, but it is better if applied to an extremity of a pipe in vertical position, while it is low with a

horizontal pipe of reduced diameter (acceptable with small diameter, 4"; scarce with greater diameter, 10" and beyond, or with a smooth surface), inadequate with short spool of large diameter (24" and 30");

- the elimination of the dusts suspension by the absolute filter is good (the filtration of micron particles is effective regarding the smokes and the air-smoke mixture present in the room);
- the smokes production is larger with the plasma torch cutting process, due to the higher temperatures involved;
- the cut temperature -and, in certain conditions (e.g., sectioning of plate pieces), also the cutting speed- can be higher by adopting the plasma torch;
- the enrichment of gaseous emissions in a closed environment increases with the cut duration (mainly because the absolute filter stops only the dusts);
- the behaviour of the micron dusts should be examined, in function of their proportion and their concentration, with a specific study on the aerosol;
- shape and sizes of the aspiration devices should be optimized in view of increasing the emission captures;
- the dust quantity inhaled by the worker is significant and it depends mainly from the following parameters: cutting work duration, material, piece shape/thickness, surface conditions, cutting methodology, distance between worked piece and worker face. Preventions - also minimal- should be taken into account, but they could be unsatisfactory;
- the dust concentrations survey should be planned to arrange the less emissive cut procedure and the necessary instrumentation locally employed in order to supply key information, e.g. on the ventilation of the cutting room and on the continuity of the dismantling.

4.2. Measures to be applied and their effect

The suggested items to be adopted during the hot cutting processes of pipes and tanks in closed environment are the following:

- a) to activate air circulation, increasing the number of air-changes per hour, introducing fresh air under pressure and eliminating fumes with monitored procedures in order to maintain cleaned, breathable and clear the room atmosphere and to allow the manual cut;

- b) in presence of a reduced number of air-changes/hour, to operate by automatic remote or manual cut with a shielding at the worker inhalation, by means of very efficient protection methods, such as: letting in of clean air directly towards the same worker; drastic reduction of the cut times in order to limit the emissions; significant increase of the suction capacity, in order to eliminate the dust by filtration, also without reducing in any case the emissions quantity in the room;
- c) to separate the room in various compartments, in which the conditions described in a) should be obtained during the cut processes, independently from the room ventilation;
- d) to isolate and transfer, if possible, components of large dimensions to other zone (or to a specific station) of the plant, where the cutting procedures could be better and securely performed;
- e) to prefer, where possible, sectioning methods of the pieces - such as mechanical cut -, which generate lower cut temperatures and thin dusts in smaller quantity.

The suggestions described in a) link to the common cutting procedures for reduced volume environments. The classic procedure for these cases is based substantially on the activation of a forced air circulation, so achieving the necessary dilution of the emissions to maintain the pollution level (environmental and/or at personnel breathing) within the advised values. The solution could not be applied for environments having a reduced ventilation capacity (e.g., one air-change per hour) that cannot be modified and adequately transformed, either because of structural problems, or due to functional and safety bonds with the outside.

The subjects linked with the hypothesis described in b) are more complex. Firstly, even if we plan a manual dismantling, a partial automatic remote cut could be required. This is the case of big components and tanks, for which – due to dimensions, wall thicknesses, arrangement of the individual cuts to carry out, limitation of the available spaces and complexity of the internals – it seems correct to adopt appropriate devices to section the walls also if with the eventual personnel assistance, but without the direct contribution of operators. An automatic device should be selected, moved by a pneumatic (or mechanic, magnetic, electric, etc.) actuator in order to optimise the working

times of the cut operations, the easiness of the arrangement in situ and, above all, the suction of the emissions to send to the filtering system (by absolute filter). Moreover, also a manual cut with a shielding at the worker inhalation, by means of very efficient protection methods (complete overalls) and a clean air flow directly towards the same worker, should be considered. This is not a simple procedure and it is not even easy to carry out and to maintain during the operation in situ, since it is largely variable and depends strictly by the considerable complexity of layout and space arrangement with very discontinuous lines.

Adequate cut times planning, to limit the emissions, can represent a suggestion and an intervention that influence more the cutting feasibility than the installations or the technologies. It concerns, naturally, the operations management to graduate its duration, succession and pieces to be put in the cut operation, taking into account the attainable pollution amount as a variable. It is not a solution to discredit and modify, after having improved cut procedures, methodologies and technologies; to plan the segmentations sequence, leaving to be driven from the local instrumentation, which measures and interprets the safety conditions for the operator, could represent a last card to play.

The last alternative described in b) appears more problematic. A considerable increase of the suction capacity could be advised, to eliminate the dusts by filtration, also without reducing in any case the emissions quantity in the room. The hypothesis of an increase of the suction capacity is valid only in the perspective of an available pump of greater capacity. It is difficult, also in this situation, to reduce the emissions quantity which can be removed with respect to that produced in the cut. It is not widely possible, in fact, to hinder the shedding of the aerosols, which are usually directed from the spread.

A feasible solution concerning point c) could advise the adoption of a “calm” room. If the separation in various dismantlement compartments is possible, the ventilation of the so obtained room could be activated to the utmost, sending off the air discharge in an appropriate volume. This is preceded by a cyclone gas washer. The air deprived of large part of the dust and, if necessary, treated to subtract the eventual dangerous parts and the micronic dust

through the absolute filter, is sent again into the original environment. A minor discharge of gaseous substances towards the outside results, in such way, since the air circulation is strictly maintained within the boundaries of the main environment, in which the ventilation is active. A mix of interventions, which is not only based on the hot cutting, is hypothesized in point e). Mechanical cut produces richer emissions of coarse dust or, analogously, with less quantity of thin and ultra-thin dusts that, once inhaled, influence negatively the human respiratory apparatus. The choice of a mechanical cutting procedure, if appropriately qualified and quite characterized above all for the effects of the created aerosols, should be oriented. This procedure should be also reconsidered either to limit the previous phenomena due to the gaseous suspensions or in connection to specific activation and intervention conditions (e.g., under-water cut). The prevention of radioactive particles dispersion imposes still greater precautions with respect to those ordinary, if the cuts concern contaminated and/or activated material. One should pay attention also to the various parameters which influence the operation, such as speed/cutting times, easiness of using the cut devices, requirement to increase the cut instrument pressure on the piece, wall thickness and material type. Tools provided with diamond edge disks, even if they mainly produce coarse dusts, seem to adapt better than other mechanical sectioning instruments like hack or band saws, in the case that mechanical sectioning is requested.

A suggestion that apparently seems antithetical with respect to the dismantling politics till now followed, could consist in transferring the large dimensions whole components in suitable cut stations, after separating the nozzles to the entrance/exit lines and, if necessary, with the support systems. The dismantlement operations can be planned and perfected in safety, following one or also more than one of the above discussed measures. The dismantling cell can be made with metallic plate airtight walls (or in wood covered with plastic laminates, or in plastic fibre) to consent the necessary air-changes in order to avoid high levels of pollution.

In relation to the measures to optimize the pollution levels, it could be underlined also that oxyacetylene and plasma cutting methods are not perfectly and entirely super-imposable and mutually replaceable, not only considering the

environmental amounts of produced dusts, but also that of the execution swiftness. We noticed that, in the cut of flat pieces, plasma torch is faster, while the oxyacetylene device reveals completely its prerogatives operating on pipelines. The weight of the cutting tool, besides, seems to advise against the adoption of plasma torch in the cut of big thickness walls, in order not to overtire the operator, which then would prolong the intervention times.

4.3. Advisable improvements

Supplementary considerations should be dedicated:

- to the interventions that seem timely and proper to make the dismantling procedures efficient and less polluting;
- to the measures to introduce in the adjustment of the cutting room;
- to the predisposition for the ventilation improvement, especially with the purpose to use all the measures able to achieve positive results on the workers and on the other personnel;
- to explore the perspective of positive effects on the dismantling of metallic parts/components of the plant.
- It can be useful to ponder on some actions feasible in the short period, always in the outlook of managing varied interventions, e.g. cut procedures and the most suitable dislocations of rooms and pieces. The following points should be considered:
- qualification of mechanical cut to use for the components typologies previously submitted to hot cutting procedures and selectively employable in the installation and in support to these processes;
- qualification of the aerosols created from thin and ultra-thin particles, especially with the aim to state and to describe their distributive spectre and a number of main effects;
- examination of automatic cutting processes to be used for components that, due to their particular features (e.g., arrangement, dimensions, forms, surface contamination and thickness) persuade against the adoption of manual operations;
- air-circulation activation procedures, also correlating secondary air flows treatment technologies (e.g., humidification and sputtering room to interfere with the thin aerosols condensation and absolute or mixed

- double filtration by using cyclone gas washers or other devices);
- market inquiries and technical checks in the environmental instrumentation field to survey the dust dragged from the cut emissions..

These and other aspects aim to emphasize the prospect of performing interventions of small extent as well, able to influence instantly and directly the cutting procedures. The influence of the above reported considerations is specific also in the work procedures organisation.

Feasibility studies should be carried out, finally, to organise a more systematic elaboration of the necessary interventions and arrange schemes with a gradual approach.

Accurate planning and management procedures for cutting, suction, ventilation and filtration, either in the decommissioning or in the operative phases, should take into account the protection of man and environment from the gaseous pollutions, by considering the following issues:

- treatments and technologies of capture and confinement of polluting substances present in the air;
- tests to determine the quality of present products and substances, to verify the efficiency of the filtering system and to analyse qualitatively and quantitatively the stopped particles;
- integrity tests of filtering barriers in situ;
- drawing up of operating procedures for measure, monitoring, management and treatment of the gaseous contaminants produced during the dismantling processes (hot cutting such as plasma, laser, oxyacetylene and lance, and mechanical cuts) of plants either in the operating area or in the workshop, in closed nuclear and non-nuclear environments;
- training of the operating personnel and predisposition of proper operation manuals related to cutting activities and suction/routing/filtration equipment and their use and maintenance;
- project critical analysis with check of the existing procedures and eventual improvement, adjustment or drawing up of new procedures for measures, monitor and surveillance of the work activities.

A final consideration should be added, concerning the investigation of materials and

components obtained from NPP decommissioning, by neutron techniques. Decommissioning should not be considered a mere activity of installation end, but also an important circumstance of availability of materials, components and worked systems submitted for years to ageing and degradation. It represents, therefore, the suggestion for a new diagnostic also to enhance safety and reliability of NPPs. The problem of the long term service of materials under extreme thermal and mechanic load, in fact, requires the application of non-destructive methods that facilitate the examination of the component condition, forecasting ageing and possible fracture. A non-uniform degradation, besides, can accelerate the advance of cracks favouring the critical reduction of the life of the component and therefore of the system [7] and a successful approach could consist in the neutron techniques [8, 9]. Neutron based investigations can be carried out on materials and parts after decommissioning, supplying eventual suggestions for the production of new components [10, 11].

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