Nitrojet®: A Versatile Tool for Decontamination, Cutting and Concrete Scabbling- 11225

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ABSTRACT

Dismantling and decommissioning (D&D) operations of nuclear sites facilities usually involve the implementation of a large number of different technologies. Most of them are dedicated to cutting, decontamination and concrete scabbling operations. Based on this finding, the Clean-Up Business Unit of AREVA decided to develop a new tool based on the use of highly pressurized liquid nitrogen and called: NitroJet® (-140°C / 3500 bar) to decontaminate, cut or scabble different types of surfaces as metals, polymers and concrete.

INTRODUCTION

D&D operations are complex; they are an important step in the life cycle of nuclear facilities. They require the use of different kinds of skills and technologies. The choice of a good one involves to take into account a large number of parameters such as cost, type and level of contamination, size and accessibility of cells which will be decontaminated, wastes production but also operators' dosimetry and one of the most important, the human element.

If we make a focus on concrete decontamination, current scabbling techniques are based on use of mechanical tools such as disk sander, bush hammer, jackhammer, water jet, planer…

Such mechanicals techniques have been successful used to decontaminate nuclear surfaces for many years. However, the efficiency and the productivity remain low (the operations could last several years for large surfaces) and many operators are required to operate in a high level contaminated atmosphere and in strenuous working conditions.

To provide new solutions to improve working conditions, to decrease the operator dosimetry as low as possible and to increase the efficiency of these operations, AREVA has worked on new technologies. The NitroJet® technology can be this one. This process, based on the use of liquid nitrogen at very low temperature and very high pressure, can be used on different surfaces (concrete, metal, polymers…) with really good results in terms of efficiency and rate. For concrete scabbling, it is possible to remove up to 40 millimeters in one pass. For the cutting application, the addition of abrasives material allows to cut stainless steel up to 50 millimeters with and interesting speed rate of 4 $cm.min^{-1}$.

After an introduction to the principles of this technology and the thermodynamics involved in the generation of a low temperature and high pressure fluid, the paper will move on the applications targeted by such technology and the results collected through a series of tests. Finally, the implementation of the technology on-site will be presented in a case of concrete scabbling. Strengths and weaknesses of this process will be illustrated compared to classic technologies. Finally, an economical assessment will be presented.

PRESENTATION OF THE NITROJET® TECHNOLOGY

This technology is based on the projection, of a highly pressurized (~ 3500 bar) liquid nitrogen jet at very low temperature (~ -140°C), directly to the surface to be treated.

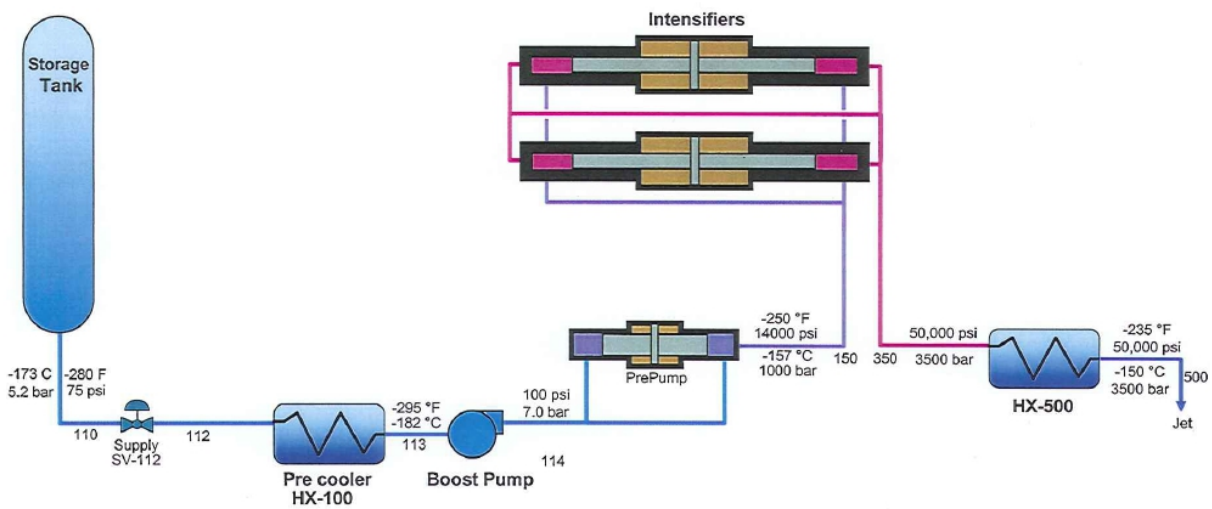
- *Nitrogen properties*

Industrial nitrogen, when purchased from gas provider, such as Air Liquide, usually holds following characteristics (Table 1)

Table I. Physical properties of nitrogen

	Nitrogen properties	Nitrogen properties required for NitroJet® technology
Pressure (bar)	4 to 6	3 800
Temperature (°C)	-175 to -180°C	-140

The scheme 1 shows the different steps of the nitrogen in the NitroJet® technology.



Scheme 1. Principle scheme of NitroJet® technology

First, nitrogen is stocked outside, in a suitable tank. In these conditions (temperature ~ -173°C and pressure ~ 5 bar), nitrogen is under liquid state. To get running the NitroJet® technology, this liquid has to be transported through highly insulated pipe to the main component of the process: the cryogenic pressurization unit also called skid. Inside, there are a combination of pumps, boost pumps and heat exchanger.

Nitrogen (entries 1 - Table II) goes through a heat exchanger (entries 2 - Table II), then through the boost pump (entries 3 - Table II). The initial pre-pump allows an increase of the nitrogen pressure from 7 to 1000 bar (entries 4 - Table II). Then the fluid goes through a crossed flows exchanger (entries 5 - Table II). This one is especially dedicated to cool down the liquid nitrogen that has just passed through the high pressure pumps. After, the nitrogen will go through the high pressure pumps. There, the pressure will be increase to 4000 bars (entries 6 - Table II).

As we have already explained above, this "hot" liquid nitrogen is cooled down inside the crossed flows exchanger (entries 7 - Table II). At this point, the liquid can be brought outside the skid through a high pressure pipes network to another heat exchanger used for raise the cryogenic temperature of liquid nitrogen (entries 8 - Table II).

At the end, the nitrogen jet is thrown through a “gun” on nuclear surfaces to be decontaminated.

Table II. Variation of pressure and temperature of the nitrogen fluid through the NitroJet® process

Entries	Pressure (bar)	Temperature (°C)
1	5	-173
2	5	-185
3	7	-180
4	1000	-150
5	1000	-90
6	4000	5
7	4000	-40
8	3900	-140

- *Nitrogen flow rate*

It is important to note that just a fraction of the nitrogen total consumption is used for the final application. Depending on the system configuration, the environment conditions (humidity, temperature…) and also the nozzles configuration (number and diameters of the orifices), nitrogen flow rate will be affected.
The flow rate at the outlet of the gun is given by a combination between the considered pressure and the nozzle configuration. Thus, the consumption of nitrogen may range from 0.18 to 2.6 $L.min^{-1}$.

DECONTAMINATION OPERATIONS

As we already mentioned, with this new technology, operations of conducing cutting, decontamination and also concrete scabbling can be done. This chapter is dedicated to the presentation of the results obtained with the new technology.

- *Concrete scabbling*

The last step in Dismantling and Decommissioning is the operation of concrete decontamination. In this context, the deployment of the NitroJet® process seems to be really interesting. Thus, AREVA-BUA decided to start a development of the technique including tests in laboratory at an industrial scale. All these tests were carried out with the NitroJet® N4 model using a “gun” with a rotating joint. It is quite important to note that Air Liquide has made research to develop a new one to increase the reliability of the tool.

Different compositions and types of concrete (vibrated and non vibrated concrete with density from 300 to 400 $kg.m^{-3}$) have been tested during those tests.
The optimal parameters to remove concrete (from millimetres up to 40 mm in one pass) with the best productivity but also the best surface state (this step of a best surface state is very important to measure afterwards the residual activity to downgrade the building.


Fig. 1. Different depths of scabbled surfaces

The different parameters experienced during this tests period were:

- temperature and pressure of liquid nitrogen at the tool exit,
- the distance and angle between the tool and the surface,
- the rotation of the "tool"
- the speed rate of the tool,
- the thickness of concrete removed

Concerning the temperature and the pressure of the nitrogen jet, we have found a correlation between both. Indeed, as we saw previously in this manuscript, higher the pressure is, higher the temperature will be. Since temperature appears to be an essential parameter for the efficiency of the NitroJet® technology (T < -100°C induced no scabbling process), a balance has been found between these two parameters. As for temperature, a minimum value of pressure is needed for the scabbling process to take place (~ 2 000 bars).

Concerning the distance between the tools and the substrate, since liquid nitrogen vaporizes quickly, it is important to have a short gap. Shorter the distance is, higher will be the efficiency. What we shown is the importance of the angle between the tool and the surface. We found that the best value was an angle of 90°.

Regarding to the nature (composition, density…) of the concrete, we show no influence of the nature of the concrete on the process. Due to the blast effect induced by the vaporization of liquid nitrogen (Table V), material with high level of cohesion will be scabbled more easily.

Concerning the speed rate of the tools, what we highlighted is the impact of the speed on the width of concrete removed (Table III).

Table III. Influence of speed rate on depth

Speed rate ($cm.min^{-1}$)	240	100	40
Rate ($m^2.h^{-1}$)	6	2.5	1.25
Depth (mm)	5	14	25

All these laboratory tests have been also realized at an industrial scale. The AREVA nuclear facility of SICN in Veurey (France) was chosen. During more than three months, we validated all the previous results and the reliability of the different equipments as described below.

As it can be observed in the table above, the rates obtained with this cryogenic technology are roughly 10 times higher than the rate obtained with conventional mechanical process. It has been possible by using the new technology in concrete scabbling and the combination of three major effects induced by liquid nitrogen (Table IV).

Table IV. Different effects occurred during NitroJet® process

Nature of the effect	Description
Thermal	Liquid nitrogen at -140°c vaporizes and causes embrittlement and decohesion of the material
Blast	Nitrogen liquid expansion by a 640 factor due to the change of state (liquid to gas)
Mechanical	High speed (~ 1000 m.s-1) allows a high level of kinetics energy

- *Decontamination*

Decontamination of various kinds of surfaces is also an important step in D&D operations. We investigated this field in the same way as we did for the previous application. Tests were carried out on stainless steel plates (500 x 500 x 5 mm) coated with different types of simulates (fixed and non fixed contamination) and also with painted steel plates: for non fixed contamination (white board ink), a productivity of more than 10 m².h^{-1} was found. (Fig.2 A/A_1) for fixed contamination (coppersmith ink), a productivity of more than 5 m².h^{-1} was found. To increase the productivity of the decontamination process, the distance between the tool and the substrate has to be reduced compared to the non fixed contamination. (Fig.2 B)

The last test has been realized with epoxy painting coated the plate. In this case, a productivity of roughly 5 m².h^{-1} was observed. The conditions of decontamination were the same as the for the coppersmith ink (fixed contamination on plates). However, this kind of coating appears harder to be removed. Small parts of painting remained after the cleaning process. (Fig.2 C/C_1)

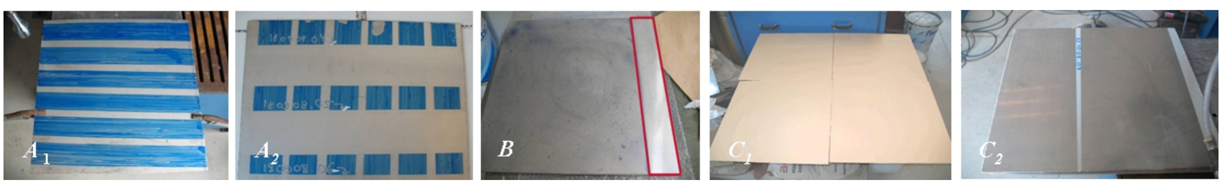


Fig. 2. Decontamination with NitroJet® on various substrates

We also carried out innocuousness tests (roughness measurements and SEM (microscopy) observations) to make sure the NitroJet® process did not induce any stress to the metal based substrate.

- Roughness measurements were carried out on 304L stainless steal sample. The left side of the sample was the one treated by NitroJet® process. We realized 1 pass with a speed rate of 30 cm.min^{-1}.

The results are listed in the table V

Table V. Roughness value

Initial value (µm)	Final value (µm)
0,24	0,20
0,36	0,34
0,33	0,35

As we can see, no change in roughness values can be observed.

- SEM analyses were carried out on 316L stainless steal sample. We realized 10 pass and the speed rate was 10 cm.min-1.

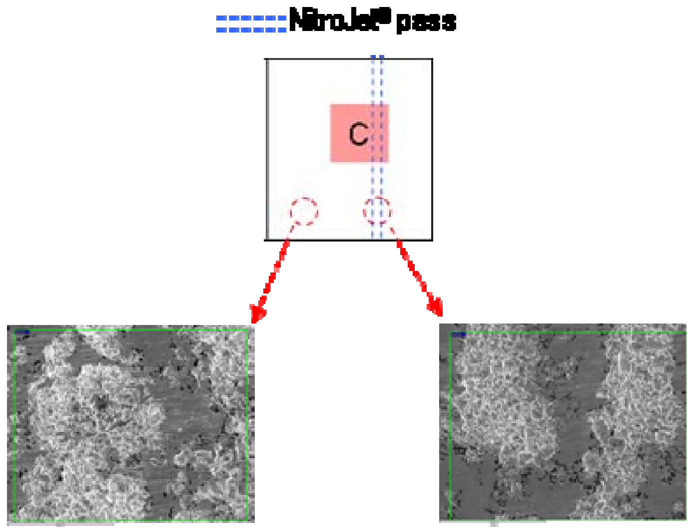


Fig. 3: SEM pictures

As we mentioned for the roughness measurements, the same observation can be done for the SEM analysis. Indeed, the comparison between the area with treatment and the one without treatment show no difference. All of these observations show that the NitroJet® technology cause no stress or modifications to the substrate: it means that the process can be used both in dismantling and for maintenance operations.

- *Cutting applications*

The last application we investigated is the cutting application that is also an important step in D&D operations. The main advantage in using NitroJet® technology for this type of applications is there is no "hot" point generation. It means that we can use it in sodium environments as fast neutrons reactors for example.
Depends on the substrate nature, an abrasive material (abrasive rate ~ 0.4 $kg.min^{-1}$) can be required. We tested different kinds of substrates as stainless steal, polycarbonate, lead, carbon steel. The thickness but also the speed rates have been listed in the table VI.

Table VI.

Material	Speed rate ($cm.min^{-1}$)	Maximal thickness (mm)	Uses of abrasive material
Stainless steel	4	50	Corindon
Polycarbonate	30	20	-
Lead	< 3	20	-
Carbon steel	10	20	Corindon

IMPLEMENTATION OF THE NITROJET® TECHNOLOGY

As we saw previously, the AREVA nuclear facility of SICN was chosen for the industrial scale tests (January to March 2009).

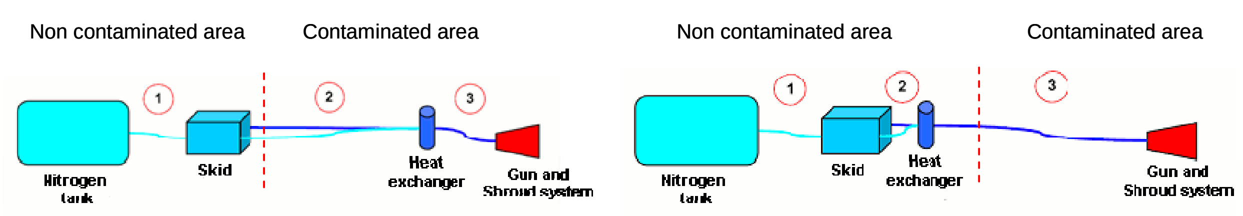
- *Equipment description*

The equipments listed in the table VII is required to run the NitroJet® technology.

Table VII. Equipments needed to run the NitroJet® technology

Equipment	Description / Function
Power utility (fuel)	250 kVA - Power supply
Nitrogen Tank	16 000 L - Nitrogen storage
Nitrojet Skid	Core of the technology
Heat Exchanger	Final cooling of the nitrogen jet
Air compressor and drier	Rotation of the nozzle, Valves powering
Insulated LP pipes	Transportation of LP nitrogen from the tank to the skid and from the skid to the HE
HP pipes	Transportation of HP nitrogen from the skid to the HE and from the HE to the Gun
Gun mounted with rotary nozzle	Distribution of the nitrogen
Two Axis Bearer (Carrier)	Motorized axis for automatic operations
Shroud system	Collection of the nitrogen and of the concrete dusts
Cyclonic vacuum system, HEPA filter	Separation of dusts; aspiration of the nitrogen, purification of the gas

Two assembly configurations can be used to run the process. In both cases, equipments such as the nitrogen tank, the skid and also the power supply utility can be located outside of the building. About the heat exchanger, it can be placed inside or outside the building depending on the chosen configuration (1 or 2). Indeed distance between skid and heat exchanger can be from 1 meter to 200 meters. Gun and shroud system should be set up within the building and nearby the surface to be treated.



Scheme 2. Possible configuration for the NitroJet® process (Left: configuration 1, Right: Configuration 2)

The shroud system is one of the most important items in the NitroJet® process. Indeed, in a nuclear environment, nuclear dissemination must be avoided. Therefore, all the particles removed from the concrete surface have to be collected by an efficient system implemented as closely as possible from the

emission point. In that way, we developed several types of collecting systems to match with all surfaces (flat surface, open and close angles…).
Captation of nitrogen, concrete plates and dusts is ensured by a complete vacuum system composed by a vacuum pump (P ~11 kW and flow rate ~ 1 100 $m^3.h^{-1}$), a cyclone head positioned on a 200 litters drum, a primary filter (porosity of 3 µm) and a HEPA filter (porosity of 0.3 µm). The efficiency of this configuration was tested for different depths. We demonstrated that more than 99% of surfaces can be scabbled.

➢ *Uses of the technology*

The control of the machine can be done by three different ways:

- manually,
- semi-manually,
- automatically.

The choice depends on the dosimetry and of the accessibility and the configuration of the cells to be decommissioned,

- The manual control involves the use of a gun equipped with two triggers. A pipe is also dedicated to the suction of dusts and nitrogen. This way will be chosen for the treatment of singularities and cramped surfaces,
- The semi-manual control consists in placing the tool and the pipe on a charge balancer. This option should be preferred for the treatment of flat surfaces and singularities and when the size of the room is not compatible with the installation of a bearer,
- The automatic way will be, when it is possible, the better way. A bearer, mounted on a railway can be used to control the speed and the direction of the jet. This configuration is useful for the treatment of walls, ceilings and angles.

➢ *Results and conclusions*

The implementation of the NitroJet® technology on SICN nuclear facility can be considered as a success. The first phase consisted in transferring, setting up, connecting and testing all the equipments was done in only one week. The NitroJet® technology was then able to run during several weeks with no major problems regarding to the maintenance. It was possible to work 5 hours long in a day. The deployment of the technology with hundreds or thousands of square meters of concrete appears viable on a technical point of view.
The three different configurations (manual, semi-manual and automatic) have been tested.
The trapping of nitrogen, dusts active particles by the vacuum system was found excellent. More than 99% of the dusts and concrete plates were trapped by this aspiration system.
Regarding to the productivity of the process, the rates obtained during the laboratory tests were also achieved uring the implementation phase with the automatic configuration.
Ultimately, the organisation and logistics to implement the new technology are easy. Most of the equipments remain outside. Only pipes, the gun and the bearer had to be moved in. Heat exchanger, depending on the deployment configuration (figure 4) can be moved inside or outside the building.
In the next chapter, we will present an economic consideration of the NitroJet® process.

R&D operations on initial NitroJet® system

Regarding the different observations from SICN (especially reliability, implementation and ergonomy), the clean-up BU decided to modify the initial system.

In that way, we worked on:

- the development of a new gun,
- the complete nuclearization of the system.

➢ *Development of a new gun*

The initial gun used in SICN showed its limits in terms of reliability, flexibility and ergonomic aspect. All these points can be a hindrance to the use of technology in high activity conditions.

To solve those problems, we decided in 2009 to start a R&D program to develop, with our partner (Air Liquide), a new NitroJet® gun (patented by Air Liquide). The results are really interesting. Indeed we have increased:

- the reliability (MTBF from 4 hours to more than a week)
- the flexibility (can afford all cases in D&D operations)
- the ergonomy in case of manual uses such as weight (7.5 to 3.5 kg)

➢ *Nuclearization of the system*

We also worked on the nuclearization of the technology which is an important point. Indeed, initially the technology was not invented to be involved in nuclear environment. Thus, we developed some efficient aspiration system to absorb the volume of nitrogen gaz and to collect, as closer as possible, dust and finally to avoid a dissemination of the contamination. We focused our development on the high pressure tubing isolation. This work allows us to have to different configurations (Scheme 2 - p.7) with a distance, between the heat exchanger and the gun, up to 100 meters. This configuration allows us to have most of the equipments outside of the contaminated zone, which is a good point regarding the economic aspect.

➢ *Conclusion*

All theses developments and improvements on the initial system allow AREVA-BUA to use this technology in high activity conditions, on large surface areas and with a manual or automatic configuration. The increase of the gun and skid reliability was a crucial point in case of commercial use. Indeed, it was difficult to imagine having to change the seals for example every 4 hours in a hostile environment like high activity's cells.

ECONOMIC

On a technical point of view, the NitroJet® technology for the concrete scabbling application has given very good results (see Table VIII) compared to the traditional mechanical processes.

Table VIII

		Floor				Wall				Ceiling		
		3	5	10	20	3	5	10	20	2	5	10
m² / day	NitroJet®	23.00	19.70	8.20	3.30	23.00	19.70	8.20	3.30	23.00	19.70	8.20
	Mechanical	10.88	10.00	2.88	1.60	3.00	1.60	0.80	0.24	1.00	0.50	0.30
	Comparison NitroJet® / Mechanical	2.11	1.97	2.84	2.06	7.66	12.31	10.25	13.75	23.00	39.40	27.33

However, this new technology is not the best technology for floor scabbling application. Indeed, the price of a floor planer which is usually used is not very high for and its implementation costs less than the NitroJet® process.
The Nitrogen technology becomes economically interesting for concrete walls and ceilings as soon as the thickness of concrete to remove is at least more than 5 millimetres and the surface higher than 500 m².
With this technology, as the efficiency of concrete scabbling has been increased compared with the other mechanical technologies, schedule of the dismantling project can be shortened. Also, financial costs can be reduced by minimizing the duration of this step
Other advantages that could have an impact on costs are:

- Concrete scabbling when carried out with usual technologies often requires changing tools when shifting the thickness of concrete to remove: disk sander for a few millimetres, bush hammer or jack hammer for more important thicknesses. The NitroJet® technology can deal with various thicknesses from a few millimetres up to 40 millimetres.
- This liquid nitrogen technology does not cause collateral damages to the metallic structure of the building. There is no vibration and the reinforcement is kept undamaged (compared to bush hammering for example).

CONCLUSION

NitroJet® process is an innovative and promising technology for D&D applications as cutting, decontamination and concrete scabbling. Since the end of 2008, the Clean-Up Business Unit of AREVA in partnership with Air Liquid accomplished interesting development to use this cryogenic technology in nuclear facilities including:

- Development of a NitroJet® gun which allows an increase of the reliability and the flexibility of the technique
- optimisation of parameters for D&D applications,
- increase of the machine reliability,
- development of an efficient aspiration system to avoid the contamination dissemination
- development of a dedicated bearer for automatic configuration

As we already mentioned, NitroJet® technology showed promising perspectives as:

- *economic*: increase of rate processing, decrease in site monitoring costs,
- *environmental*: use of an inert gas, no secondary waste generation, non use of chemical, dry process,
- *social*: less strenuous work, decrease of operator dosimetry which is compatible with ALARA principle.

The next step is a real test in very hard conditions, in a specific cell. This test is going to take place in spring 2012 in AREVA nuclear reprocessing facility of La Hague (France) to accomplish concrete scabbling applications. This test will be the last of a long development period before commercialization.

AKNOVELEDGMENTS

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