# WOW TECHNOLOGY's Innovative Radioactive Liquid Waste Treatment - 16128

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## ABSTRACT

WOW presents its revolutionary technology and equipment for liquid radioactive waste treatment: outperforming ultimate water decontamination and purification process, enhanced sludge concentration, no secondary waste nor consumables, fully automated, remote controlled and self-decontaminating device.

The WOW's technology is based upon a never before observed discovery of fluid dynamics science: the possibility of performing a molecular separation between solute and suspended elements and the solvent. The combination of such a molecular separation process with a standard vacuum evaporation improves the abatement performances by thousands of times, with respect to those of the state of the art vacuum evaporators. In addition to this, no secondary waste is produced during the process, as no filters, membranes, resins or additives are used. WOW equipment, automated and remote controlled, self decontaminates after use and can be designed and constructed either tailored to the application needs or with a modular approach for enhanced transportability and application flexibility.

After the preliminary verification by CNR, the Italian National Research Center, WOW TECHNOLOGY's decontamination device was tested c/o LENA, the Laboratory of Applied Nuclear Energy of the University of Pavia, Italy with a simulated solution 6000 times more contaminated than the nuclear reactor's cooling water of Fukushima-Daiichi NPP. In addition to that, WOW's technology was also used in a real case at the Radiochemistry laboratory of the Pavia's University Chemistry department. Both the above mentioned contaminated fluids have been successfully decontaminated without production of additional or secondary waste.

WOW's technology has already performed on industrial scale c/o the Nuclear Repository of S.S.M. in Saluggia, Italy: 45000 liters of acid radioactive solution have been successfully decontaminated to a Decontamination Factor (DF) of 335000 for Cs-137 by one single evaporation step and without using any additional tool to control steam. [Performances independently certified by: National Physics Laboratory (UK) and Pavia University Radiochemistry Laboratory, Chemistry Department (Italy)]. The high decontamination factors and the high volume reduction of the sludge make this technology suitable for the ultimate treatment of highly contaminated liquid waste such as the Fukushima-Daiichi nuclear reactor's cooling water.

The WOW's technology addresses as well to interventions in both, operating and decommissioning nuclear power plants and any other nuclear and radioactive facility whose produced and/or stored radioactive liquid solutions, including acid liquid solutions, can be successfully treated, the waste volume reduced and no secondary waste produced.

## INTRODUCTION

The treatment of the radioactive liquid waste forces to face with serious problems:

1. Radiation protection of workers, population and environment;
2. Need of a dramatic volume reduction of the final disposed waste;
3. Production of additional secondary waste (filters, membranes, resins, additives, etc.);
4. Pursuit of liquid treatment with high decontamination factors and declassification of separated water;
5. Chemical aggressive and hazard conditions (e.g., in case of decontamination of acid liquids);
6. Coexistence of physical, radiological, chemical and bacteriological hazards.
7. Accessibility of to the hazardous waste disposal facilities;

WOW's technology is a solution to such problems:

1. Fully automated and remote controlled equipment for the reduction of the operational dose;
2. Decontamination of liquids and concentration of contaminated liquids far from the heated parts of the evaporator, so it eliminates limits to the maximum concentration factor;
3. No use of consumables such as filters, membranes, resins, additives, etc., so no production of additional secondary waste;
4. Decontamination factors thousands of times higher than with standard evaporator technologies or with any other treatment process;
5. Possibility of selecting the device built-in materials or coatings to manage any chemical environment and conditions;
6. Extraordinary effective with radionuclides, chemical contaminants, bio contaminants, suspended solids, etc.
7. Treatment device can be built on a tailored scale or in easily transportable modules, fitting in standard containers.

The WOW's technology originates from a crucial discovery made by the founder of WOW Technology while developing an innovative water purification system. The discovery consists in the possibility to control local physical properties in a fluid inside an evaporator by medium of a patented internal tool and a specific control software. The first results immediately suggested to test the applicability of the WOW's technology to more stringent operating conditions, such as those related to liquid radioactive waste. And the tests gave fully positive result.

## DESCRIPTION

The WOW's process is the combination of a standard evaporation/distillation process and a new fluid dynamics technology that allows to separate liquid solvent from solute and suspended components of a solution.

The theoretical base is a unique and solid high order physical theory on transformation of a liquid solution from homogeneous to dis-homogeneous. The technology developed by WOW controls such a phenomenon through an active process, so to either **cancel or amplify the entrainment or "drag" effect of any evaporation process, that is an unwanted secondary effect usually limiting the actual performance of distillation and evaporation processes.**

As a consequence of the above described controlled phenomenon, the application of the WOW's technology to a standard evaporation system dramatically enhances the separation performance with respect to that of the evaporator alone. Moreover, the localization of the WOW's contaminants concentration process in the very center of the processed solution volume prevents the superficial contamination of the boiler and eliminates the need of additional upstream and downstream tools like demisters, filters, membranes, distillation columns, bubble caps, reflux, liquid-vapor coalescers etc. The WOW's control of the drag/entrainment effect of the evaporation process brings to Decontamination Factors (DF) hundreds to thousands times better than any other decontamination process. As the key is a physical phenomenon correlated to the liquid properties more than to the evaporation process itself, and it is not a chemical phenomenon, no consumables nor additives are used. To allow the control on the drag/entrainment effect in the evaporation volume, a pilot of the local thermodynamic parameters of the boiling solution is needed. The "bridge" between the external control panels and the remote proprietary control software from one side and the local thermodynamic parameters (not the extensive such as temperature and pressure) is an especially designed, patented and, by now, secret stainless steel tool submerged in the liquid inside the boiler (see **Figure 1**)

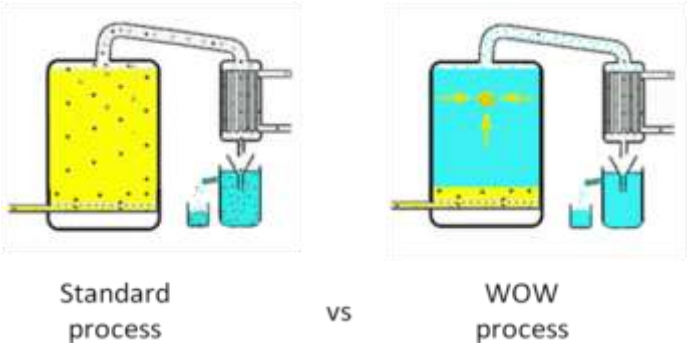


*Figure 1 - WOW's concentration process graph*

A total of 6 different parameters are controlled during this process patented by WOW Technology (PCT/IB2010/052342).

The WOW's system separates solvent (e.g. water) from its solute or suspended elements/contaminants regardless of their nature (microbiological elements like bacteria, viruses, protozoan, pathogens, parasites and toxins; chemical solid contaminants; chemical liquid contaminants, including volatile elements; any other water pollutants) and it concentrates the residuals by several orders of magnitude better than any currently known method, , greatly reducing waste storage volumes and management costs. The WOW's process is fully described by a mathematical predictive model specifically developed by WOW TECHNOLOGY's engineers; this allows WOW to design scaled up versions of its device tailored to any application. Based upon the above mentioned mathematical model a dedicated operative protocol for each single application is prepared. Starting from the chemical and physical analysis of the solution, the protocol is triggered to grant the decontamination process to reach the following two targets: requested purification level of the output liquid/water and the final reduction of residual waste volume.

The whole decontamination system (WOW's process plus the standard evaporation) is a continuous and single step process. In fact, since the evaporative process is applied to a dis-homogenous liquid (product of WOW piloted phenomena), with full control of the drag/entrainment effect, no batches are required to reach the desired DF. Moreover, as the concentration of the separated residuals happens in the volume of the liquid and the cleaning of fouling deposits is easily performed by a simple water washing at the end of the activity. In addition to this, due to construction method simplicity, almost no maintenance is required on this device.

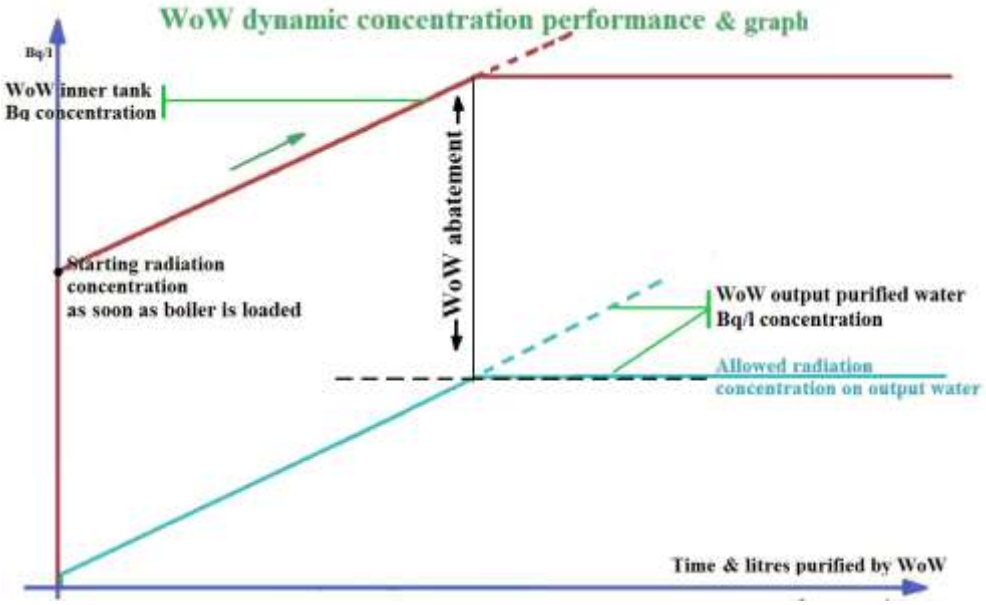


*Figure 2 - WOW's concentration process graph*

In order to properly operate the equipment, the solution concentration level inside the boiler is constantly kept at the desired value by the WOW's operative protocol, that consider , among others, the physical and chemical characteristics of the solution and its radioisotopes. As described in **Figure 2**, WOW's device will reach a maximum level of contamination concentration inside the boiler and then this level will be maintained constant and stable during the whole process. By this way, WOW Process becomes a continuous process. The WOW process can be finally synthesized as a three streams process (**Figure 3Error! Reference source not found.**) combining a WOW Technology's patented process with a standard evaporation in order to obtain unprecedented decontamination factors and minimize residual waste volumes.


*Figure 3 - WOW process three streams*

## REAL CASE APPLICATIONS

### University of Pavia – L.E.N.A. - First certified application

University of Pavia (UNIPV) and its Laboratory for Applied Nuclear Energy (L.E.N.A.) cooperated with WOW TECHNOLOGY's team to certify the process for application in the nuclear industry.

The first experience was set up in a controlled environment aimed to simulate a contamination by 137Cs 6000 (six thousand) times higher than that registered in the Fukushima-Daiichi reactors cooling water after the 2011 disaster. **Table 1** shows the operation parameters, while

**Table** 2 shows the certified performances.

*Table 1 - Parameters and conditions of the first WOW application at L.E.N.A. - UNIPV*

| | |
|---|---|
| Continuous Operation: | 20 liters/day for 39 days = 780lt |
| Contaminants Concentration: | 1,500 mg/l of 133Cs totally solute + 2 radioactive tracers: 134Cs (4.2MBq) few µg, 137Cs (3.6MBq) few µg |
| Conc. Level Simulation: | 4.8 TBq/l typical of HLW |

*Table 2 - Certified performances of the first WOW application at L.E.N.A. - UNIPV*

| | |
|---|---|
| Min. Decontamination Factor | DF > 7,500 |
| Removal efficiency: | 99.986% |

### University of Pavia – Second certified application

A further application of WOW process was performed at Radiochemistry labs of UNIPV's Chemistry department to decontaminate 1000 (one thousand) liters of low level contaminated solution used in the anterior 30 years to clean radiological contaminated items. **Table 3** shows parameters of this second application,

**Table** 4 shows the second application's certified concentration performance and while table 5 shows the decontamination factors certified by L.E.N.A. – UNIPV labs.

*Table 3 - Parameters and conditions of the second WOW application at L.E.N.A. - UNIPV*

| | |
|---|---|
| Quantity of treated liquid: | 20lt/day x 50days = 1,000lt |
| Contamination Level: | few Bq/L for each radionuclide |
| Radionuclides in solution: | 137Cs, 134Cs, 60Co, 241Am, 109Cd |

*Table 4 - Certified concentration performance of the second WOW application at L.E.N.A. - UNIPV*

| | |
|---|---|
| Final Radioactive Waste: | < 1lt of concentrated sludge |

*Table 5 - WOW unit "WOW PUT 1.0" used in the second application at UNIPV – Radiochemistry labs*

| Radioisotope | Measured Decontamination Factors (DF) |
|---|---|
| 137Cs | 40338 |
| 134Cs | 39744 |
| 241Am | 33425 |
| 109Cd | 18735 |
| 60Co | 7581 |

**Note:** What reported in this

is the "static "or "relative" Decontamination Factor performance as defined in Literature on evaporators: an a-dimensional number that is the ratio between the concentration inside the Boiler, where the evaporation is performed, and the Outlet concentration. Dynamic Decontamination Factor, instead, is an adimensional number that represents the ratio between "Inlet concentration" and "Outlet concentration" i.e. the Total DF = Cinlet / Coutlet.


*Figure 4 - The three streams of WOW process in the second WOW application at L.E.N.A. – UNIPV*


*Figure 5 - WOW unit "WOW PUT 1.0" used in the second application at UNIPV – Radiochemistry labs*

## Full scale application c/o the Nuclear repository of Saluggia

The nuclear waste repository in Saluggia (Vercelli, Italy), located about 30 kilometers North-East of Turin, dealt with 50,000 liters of polluted solution at pH=4.6. Originally produced during the decommissioning of the nuclear site aside, it had been accumulated along over 30 years. The pollutants, apart from several

salts and surfactants, included the following radioisotopes: 241Am, 137Cs, 60Co, 90Sr.

WOW TECHNOLOGY was contracted by the operator of the site to properly treat the above mentioned contaminated water and with the following aims: separation of pure water with negligible residual contamination that required accurate low-background measurements and concentration of the remaining pollutants into only 20 liters of concentrated sludge. WOW TECHNOLOGY designed and built a dedicated scaled up version of its equipment, calling it "Moses WOW-Demo 1.0", that was used in combination with the shielded prototype "WOW Put 1.0", used as sludge dryer (see following **Figure 6**).


*Figure 6 - from left to right: disposal tanks of liquid to be treated, "Moses WOW-Demo 1.0" unit and the dryer "WOW Put 1.0" unit here installed*

This unit, that is an evaporator module with 1000Lt/day of treatment capacity, operated at only 25-27Lt/hour due to the site energy constraints. This unit has obtained all the safety approvals and it has been certified as a **fault tolerant and failure proof device** (evaluation performed by analyzing FMEA - Failure Modes and Effects Analysis - and all 101 possible different device's functioning statuses). For each failure mode has been analyzed potential effects of the controlled Failure and/or counter-measures actions by an evaluation of RPN number ranking (Risk Priority Number) before (without controls) and after implementation of countermeasures. The unit has been designed and certified to be fully transportable in a standard container and to be stacked up vertically up to a number of five units to work as a single device. Such a modular configuration, while granting to perform at the highest reliability levels, reduces the platform area Since September, 2014, WOW's module operated uninterruptedly for 120days, continuously monitored by nuclear repository owner (SSM) and certified by two advisors: L.E.N.A. – UNIPV and by the British National Physics Laboratory (N.P.L.). Initial contents of the liquid solution were: pH = 4.6; Fluorides <1mg/l; Chlorides ≈15mg/l; Nitrates <5mg/l; Sulfates ≈303mg/l; Phosphates Absent; Sodium ≈22mg/l; Potassium ≈11mg/l; Magnesium ≈6mg/l; Calcium ≈94mg/l. For final Decontamination Factors see

**Table** 6.

As shown, the real DF for 137Cs of the scaled up device improved, from the original value of 7,500 (see **Table 1**) up to 335,000 (three hundred thirty five thousands) (see

**Table** 6), despite the worsened conditions, due to the acid solution. The DF performance can be increased even up to DF = 1,000,000 (one million) if the WOW's decontamination process is applied with solutions having pH≈7.

Table 6 - "Moses WOW-Demo 1.0" unit performances at Saluggia measured by UNIPV-LENA and N.P.L.

| **Radio-nuclides** | **Decontamination Factor (DF) after, respectively:** | | | |
|---|---|---|---|---|
| | **30 Days** | **60 Days** | **90 Days** | **120 Days** |
| $^{137}Cs$ | 80,000 (**)(^) | 142,000÷168,000 (**) | 107,000÷412,000 (***) | 335,000 (**)(^^) |
| $^{60}Co$ | 56,000 (^) | 161,000÷178,000 | 520,000÷685,000 | >890,000 (*)(^^) |
| $^{241}Am$ | >23,000 (^) | >5,290; >238,400 (*) | >300,000 (*) | >> (*)(^^) |
| $^{90}Sr$ | >2,044 (^) | >26,200 | >66,760; >96,000 (*) | >91,470 (*)(^^) |
| Notes to table 6: (*) output activity much lower than MDA; (**) Uncertainty 3%; (***) Measures conducted on several samples: output activity is very, very low and concentrated solution of the boiler has some sediments; (^) NPL did not issue here any test report (ND); (^^) Test at NPL labs is still ongoing. | | | | |

## FURTHER APPLICATIONS

The WOW's process can be useful to push the nuclear and radioactive sites decontamination beyond its present limits. In fact, the treated, uncontaminated liquid obtained through the application of WOW's technology can be reutilized or discharged or disposed of as a conventional waste, while the residual contaminants, reduced down to a much smaller volume, can be safely disposed of as solid waste, with less economic impact on the nuclear industry.

As a benchmark for this statement, we hereto propose the case study that WOW TECHNOLOGY performed on the Fukushima Daiichi reactors cooling water. Such a study is based upon the information reported in the public domain documents listed in the section "references" of this paper and the technical specification of ALPS water treatment system currently used at Fukushima Daiichi plant.

## Application study of WOW Process to Fukushima Daiichi reactor cooling water

In order to study this real case, WOW TECHNOLOGY worked with the reference parameters of the following **Table 7**.

*Table 7 - Parameters used for the study of WOW application at Fukushima Daiichi case*

| | |
|---|---|
| Water volume to be purified every 120days | 100.000 $m^3$ |
| Inlet contamination level: | 830 MBq/l |
| Contaminant agent: | 137Cs (26kg in total) |
| Allowable activity in water after treatment: | 300 Bq/l |
| Required Decontamination Factor (DF): | 2.77 x 10^6 |

With reference to the WOW process experimental and full scale Decontamination Factor (DF) ≈ 330000 (three hundred thirty thousands), the following feedback cascade configuration & control of concentration has been designed (**Figure 7**).

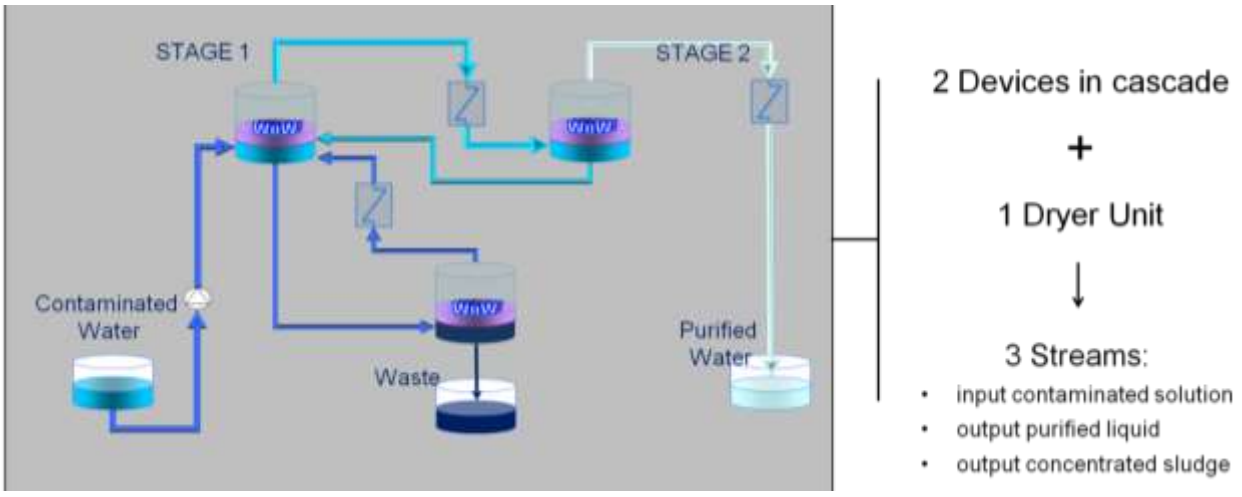


*Figure 7 - WOW process simulation for study of Fukushima Daiichi case*

To prevent WOW devices from operating at too high concentration value, each WOW device will reach a pre-determined level of contaminants concentration that will be then maintained constant and stable during the entire process (see **Figure 2** at the beginning of this paper). As a consequence, the overall DF for the two WOW's equipment in cascade is expressed by the following formula:

$$Total\ DF\ Formula = \frac{(DF\ stage1) \times (DF\ stage2)}{(relative\ concentration\ stage1) \times (relative\ concentration\ stage2)}$$

Note: The concentration mentioned in the formula expresses a relative concentration versus the first initial concentration of the solution loaded into the boiler ($C_0$), and it is an adimensional number. Actually, it is the ratio between

the concentration of the solution running into the boiler and $C_0$ [ Rel. conc. stage 1 and 2 = K = $C_{boiler}$ / $C_0$ ] where K is the max stage concentration number taken for each equipment (see below K = 250 and K = 130).

Without considering any pre-evaporator and post-evaporator device, WOW Technology assumed the following treatment flux:

| | | |
|---|---|---|
| 1st WOW device: | 980m³/day | (max stage concentration = 250) |
| 2nd WOW device: | 840m³/day | (max stage concentration = 130) |
| 3rd WOW dryer: | 45m³/day | (max stage concentration ≈ 63) |

*Table 8 - WOW process expected results in application to Fukushima Daiichi case*

| | |
|---|---|
| Total volume of contaminated water fed to WOW: | 100.000 m³ |
| Purified water output (max 300Bq/l) | 99.992 m³ |
| Final volume of concentrated waste (*) | 8 m³ |
| Final total waste volume ratio: | 12.500 |
| Note (*): where practically all the contamination is concentrated and removed from initial solution. 8m³ is the minimum volume that can be reached as in this case the concentration of $^{137}$Cs radioisotope is 3.23gr/l and so its decay is producing a self-heating up to 26 °C.<br>Considering current decontamination solutions the total DF parameter obtained with this WOW configuration is at least 10,000-13,000 times, according to public data reports, greater than with the currently used systems. | |

The expected performance for every 120days operation cycle, based upon the results of detailed computations with two effective WOW devices in cascade (considering real DF = 335000) + 1 dryer for volume reduction, are displayed in **Table 8**.

## WOW advantages versus standard distiller and perspectives

The sound DF values reached with the WOW's technology will change the perspective of application of the evaporation methods.

A standard distiller/evaporator shows, as reported in literature, DF values of only approximately 100 to 150. Even if standard additional distillation enhancing tools (such as demisters, distillation columns, bubble caps, refluxes, etc.) are adopted, if not regularly cleaned, a DF reduction is registered.

*Table 9 - WOW process performance vs. reverse osmosis and standard evaporators*

| Process: | REVERSE OSMOSIS | STANDARD EVAPORATION | WOW |
|---|---|---|---|
| Principle | membrane filtering | standard evaporation | standard evaporation + entrainment control |

| Device configuration | Pressure device | Pressure standard evaporator | Pressure standard evaporator + additional special control |
|---|---|---|---|
| Capacity | No capacity limitation | In principle no capacity limitation | In principle no capacity limitation |
| Material | Key elements: polymers | Stainless steel or special alloys | Stainless steel or special alloys |
| Performance | DF typical: it doesn't work | DF typical: 100 ÷ 300 | DF = 335000 with acids; DF = 1000000 with water |
| Utility | Standard | Standard | Standard |
| Maintenance | High | High | Very low |

WOW does not need any of these additional tools; therefore, differences and advantages between WOW's system and standard evaporators can be analyzed by considering just the following DF difference: DF=100÷150 for standard evaporator vs DF=335000 for WOW. The following advantages of WOW process are the most evident: reduced need of multiple stage evaporators; continuous activity versus the batch activity of standard evaporators; and the absence of equipment besmirchment. For a complete comparison with other systems, such as Reverse Osmosis, see **Table 9**.

## CONCLUSIONS

We are convinced, based upon the experimental and full scale application results, that the WOW's process for liquid solutions molecular separation will be the future for nuclear industry applications. As a consequence of the WOW's process performance, the operative and capital expenditures (OPEX and CAPEX) of a decommissioning activity can be significantly reduced and performances range extended resulting in a safer operation for all the people involved as well as for the citizens.

Thanks to WOW's process, the use of pickling liquids to decontaminate surfaces of nuclear plants (pipes, equipment, etc.) can be widely applied as the exhaust liquid can be properly decontaminated by WOW's process and the residual waste volume can become really negligible compared with what produced by the presently applied methods.

## REFERENCES.

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