

The D&D program of GB1 Gaseous Diffusion Plant – 14452

F. CHAMBON *, J. BONNETAUD **, P. SEURAT **, R. VINOCHÉ ***, S. DUMOND ****

* AREVA Federal Services, Columbia, MD21045, USA; frederic.chambon@areva.com

** EURODIF PRO, site du Tricastin, Pierrelatte, France; jacques.bonnetaud@areva.com;

Philippe.seurat@areva.com

*** AREVA D&D Business Unit, Tour AREVA, Paris La Defense, France; richard.vinoche@areva.com

**** AREVA Enrichment Business Unit, Paris, France; serge.dumond@areva.com

ABSTRACT

Commissioned in 1979, Georges Besse 1 (GB1) was the first commercial uranium enrichment plant in France. It is owned by EURODIF, of which AREVA is a 60% shareholder. The plant used the gaseous diffusion technology to enrich the uranium (gaseous UF_6) up to 5%.

The plant extends over 250 hectares and consists of 1,400 stages of enrichment that are distributed into 70 groups of stages. This entire plant configuration is called “cascade”. Each stage comprises 3 main parts: the diffuser, the compressor and the heat exchanger. These 70 groups are installed in 4 buildings of various sizes linked by a 900 m long gallery.

The plant, shut down in June 2012, is currently undergoing a huge decommissioning and deactivation program. An extensive physical and radiological characterization of the cascade and testing program was performed in order to define the best D&D scenario, while taking into account the main drivers of the program which are:

- Reduce the dismantling costs by maximizing very low level waste,
- Increase dismantling operations safety by decreasing criticality, contamination and chemical risks.

It quickly appeared that hot Chlorine Trifluoride (ClF_3) rinsing operation was the most efficient process to reach the level of decontamination needed to satisfy the objectives. A technical and economic analysis was performed to weigh costs and benefits of ClF_3 rinsing operation and further decontamination steps. The deactivation approach retained is systematic with the objective to always secure the same end state allowing smooth subsequent dismantling operations.

The D&D scenario of GB1 is composed of 4 main steps:

- 1/ Ending enrichment operations. The objective of this phase is to remove as much UF_6 as possible during the shutdown of the plant.
- 2/ Cleaning Process Equipment. Hot gaseous ClF_3 is used to rinse the cascade and to remove the residual uranium deposits. It's then treated with humid air to extract the fluorinated and chloro-fluorinated components generated during ClF_3 rinsing operations.
- 3/ Dismantling Process equipment. After the removal of the diffusion stages, the diffusers are dismantled and the ceramic barriers are crushed. Waste is treated and conditioned in the appropriate waste packages to be disposed of in the final repository.

- 4/ Cleaning building.

Step 1/ is already completed and step 2/ is ongoing. The first lessons learned, following the first months of ClF_3 rinsing operations, will be shared.

INTRODUCTION

The Georges Besse 1 (GB1, see Fig. 1) plant, located at Pierrelatte in the Rhone Valley (France), was the second uranium enrichment plant in France and the first one entirely dedicated to civil applications. It is owned by EURODIF, of which AREVA is a 60% shareholder.



Fig. 1. The GB1 plant

The plant was partially commissioned in 1978, with full scale industrial operations as of 1982. It used the gaseous diffusion technology to enrich the uranium (gaseous UF_6) up to 5% and was able to produce 10.8 MSWUs at full capacity. During its operation, the plant provided more than 25% of the SWUs (about 10 MSWU) produced each year in Western countries. That figure represents the enrichment services required to make fuel for one year for 100 light water reactors.

The GB1 Gaseous Diffusion Plant (GDP) extends over 250 hectares (618 acres) and consists of 1,400 stages of enrichment that are distributed into 70 groups of stages. This entire plant configuration is called “cascade”. Each stage comprises 3 main parts: the diffuser, in which isotopic separation occurs through porous ceramic barriers, the compressor which circulates the gas and brings it to the required pressure and the heat exchanger which removes the heat generated by the compressors. These 70 groups are installed in 4 buildings (#110, 120, 130 and 140) of various sizes linked by a 900 m long gallery and covering about $190,000 \text{ m}^2$ ($2,000,000 \text{ ft}^2$). There are 3 sizes (USG, UTG and UFE) of diffusion stage located in the plant (see Fig.2). The largest one (USG) is 21 meters high and weighs 130 metric tons.

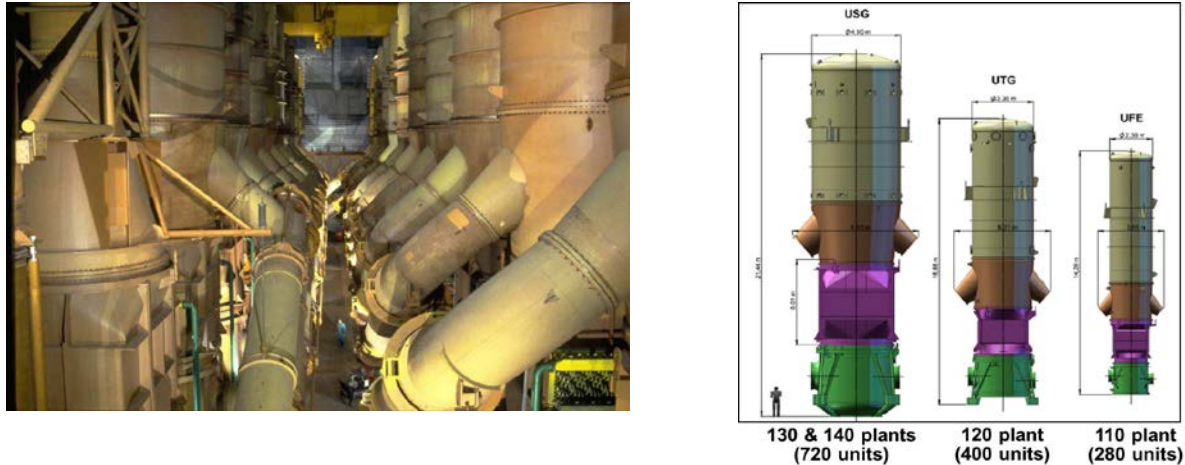


Fig. 2. The diffusion stages

After more than 30 years of operation, the plant was permanently shut down on June 7, 2012. AREVA, which already successfully decontaminated and dismantled the first military dedicated GDP (UDG plant, [1]) in France, is in charge of the Decommissioning and Dismantling (D&D) program of the GB1 plant.

The D&D approach and strategy developed by AREVA is based on the following main objectives:

- Reduce the dismantling costs by
 - Avoiding subsequent decontamination steps after the disassembling of the diffusion stages,
 - Maximizing the quantity of Very Low Level Waste (VLLW) to be stored at the CIREX (the dedicated repository for VLLW) in the North-East of France in order to favor the less expensive waste disposal solution available in France for nuclear waste;
- Increase the safety of dismantling operations
 - Nuclear safety by decreasing criticality and contamination risks,
 - Industrial safety by reducing chemical risks (i.e. uncontrolled HF release);
- Recover uranium trapped within the cascade for subsequent use;
- Reduce Surveillance and Maintenance (S&M) costs of the plant during the entire duration of the program.

Taking into account these objectives, the D&D scenario of GB1 is composed of 4 main steps:

- Ending Enrichment operations: May-December 2012,
- Cleaning Process equipment: June 2013 through the end of 2015,
- Dismantling Process equipment: 2012 to 2032,
- Cleaning Building; 2033 to 2035.

These four steps are described more in detail in the following sections with a focus on the ongoing cleaning phase.

ENDING ENRICHMENT OPERATIONS

The objective of this phase is to remove as much UF₆ trapped within the cascade as possible. With this aim in view, the gaseous UF₆ is extracted by purging the cascade under vacuum. The cascade is then maintained under an atmospheric pressure of Nitrogen.

The main constraints were :

- Not exceeding the authorized enrichment level per area during the gradual shutdown of the plant,
- Maintaining an optimum shutdown rate according to the possible letdown flow rate (UF₆ cylinder filling),
- Avoiding any risk of crystallization of the UF₆ after groups shutdown.

The shutdown occurred in two phases:

- Phase 1 « dynamic », from May 14 through June 7, 2012: a progressive decrease in production (800 to 0 MW) and successive group shutdowns. For each group, from the initial state (compressors in rotation under minimal UF₆ load), it means:
 - Stopping Compressors,
 - Transferring the residual UF₆ load of the shutdown group toward the part of the cascade still functioning by suction through low pressure pipes,
 - Isolating group and extracting of UF₆ toward dedicated units and filling cylinders,
 - Avoiding any risk of the UF₆ being crystallized (no more thermal output) with a waiting phase under residual pressure of less than 20 mbar UF₆;
- Phase 2 « static », from June 2012 through December 2012: full drainage of each group and purging with nitrogen. At the end of 2012, all groups were shut down and were under azote pressurization.

CLEANING PROCESS EQUIPMENT

An extensive physical and radiological characterization of the cascade and testing program was performed in order to define the best D&D scenario, while taking into account the main drivers of the program. Considering the large quantity of waste (about 180,000 metric tons) expected during the dismantling operations, the minimization of the waste management cost is one of those drivers. Maximizing the quantity of Very Low Level Waste to reduce the final disposal cost was identified as being an efficient solution, with, however, the constraint in respect to the waste acceptance criteria (which are a total U mass under 20 metric tons and each waste package with less than 100 Bq/g). Another important driver is to perform the dismantling operation by guaranteeing a high level of industrial and nuclear safety. Indeed, due to the large quantity of Uranium trapped in the cascade after the shutdown of the plant, minimizing the risk of criticality and uncontrolled fluorhydric acid release is of vital importance.

Initial conditions

The knowledge of the initial conditions is always crucial in order to define a credible D&D scenario. In the case of a GDP, it consists mainly of determining conservatively the contamination level of Uranium

(and its isotopic enrichment value) within the cascade in order to set up a model of contamination for the whole plant.

After more than thirty years of operation it was likely that the Uranium hold-up within the process equipment was sizeable. Indeed, the cascade operates with UF_6 which reacts with metal to form a thin coating deposit (a diffuse contamination) solid UF_4 on the walls of the process equipment. In case of leaking, UF_6 reacts also with moisture contained in air to form solid deposits of UO_2F_2 . Gaseous UF_6 is also trapped within the porosity of the ceramic barrier.

So an investigation and characterization program was launched. The idea was to build a data base for each process equipment comprised of the physical characteristics (i.e. materials, mass, exchange surface with UF_6), the radiological data, the drawings and the localization in the facility in order to have a U mass/isotopic value/radionuclide cartography of the cascade.

The first step was to analyze the available documentation such as:

- Equipment list and description (drawings, specifications...),
- Material design: type (aluminum, nickel, carbon steel and stainless steel) and elaboration process,
- Maintenance files/notes and incident report,
- Lessons learned from operations,
- Sampling and online analysis results (Chemical, physical, radiological).

The information gained during this first step was then used to define the investigation and characterization program of all the process equipment and piping within the cascade.

To do the cartography of the extent and origin of the U contamination within the cascade, NDA measurements were used as well as sampling and characterization methodology on different process equipment (diffuser, barrier, compressor...). AREVA also developed a tool to characterize the residual uranium deposit within the diffusers and the diffusion barriers. This specific device (see Fig 3.), introduced into the diffuser from the top, was able to perform in situ radiological investigation (gamma spectrometry) as well as a 360° televisual inspection on the whole height of a diffuser.

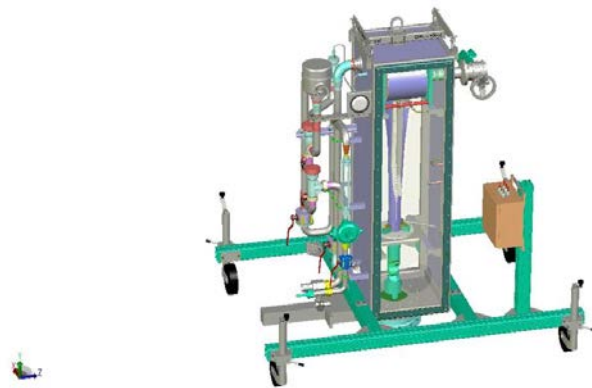


Fig. 3. The in situ inspection device

The characterization work was also done before and after testing the rinsing with Chlorine Trifluoride (ClF_3) in order to estimate the quantity of Uranium that could be removed.

The results of the investigation and characterization program showed that the greatest quantity of uranium was trapped within the metal corrosion layer.

As 1 m^2 of steel is able to immobilize several kg of solid Uranium (one mole of Fe can form FeF_3 or FeF_2 and trap 2 or 3 moles of Uranium UF_4 or UF_5), the quantity of trapped U within the GB1 cascade was reassessed to be on the rise. No corrosion issue was observed during the D&D of the UDG military plant as the metal used for the diffusion stage was mainly aluminum.

The origin of the trapped Uranium (estimated at about 200 metric tons of U) within the GB1 cascade is given here after. It is mainly a diffuse contamination (thin coating on the metallic walls of the process equipment) and a contamination in the metal corrosion layer (see Fig. 4). The later mainly affected the metal belts around the diffusion barrier bundles. It is also, to a lesser extent, a contamination within the barrier. On the other hand, there is very little UO_2F_2 due to air entry incident.



Fig. 4. Corrosion of the Ni plated metal surfaces

Process adjustment tests

Due to the large amount of Uranium immobilized within the cascade, it quickly appeared that the hot ClF_3 rinsing operation for the whole plant was the good deactivation approach to reach the level of decontamination needed to satisfy the objectives of the program. Hot ClF_3 fluorinates the solid uranium compounds present and removes them as UF_6 gas. Therefore it's a very efficient process to remove the Uranium trapped within the process equipment. It is especially interesting for the treatment of the area with a high quantity of U deposit and/or where the Always Safe Mass (ASM) is not guaranteed (criticality risk).

AREVA was familiar with this process which was already used to retrieve Uranium during the deactivation of the high enrichment part of the UDG military plant but also used on a regular basis during the GB1 operation years. A blend of $\text{ClF}_3 + \text{F}_2$ was also considered as an efficient process considering the experience in Great Britain at the Capenhurst GDP and the US experience at Portsmouth GDP [2].

Different process parameters were taking into account for the deactivation of the GB1 plant like pure or blended ClF_3 , number and duration of treatments, pressure, temperature, compressors rotation or not and additional gas;

A testing phase is important to determine the process parameters and the kinetics of the ClF_3 operations and, finally, to enhance the reliability of the cost and schedule of the program but also for the safety of the operations. It will give us the necessary data to prepare a sound D&D program and design the best waste management strategy. The quantity of ClF_3 to be used could be a huge cost driver; that's why the testing phase enables us to define the best compromise between ClF_3 cost (and risk associated with the use of large quantity of ClF_3 and cost of treatment after using) and the decontamination efficiency. The testing phase is also an opportunity to identify the process and characterization/analysis equipment to be kept operational as well as the gap to be filled.

Consequently, an extensive and representative testing program (with various parameters) to assess the efficiency of ClF_3 rinsing operations on solid uranium deposit removal was launched. Seven sets of diffusion stages were characterized before and after ClF_3 rinsing using the in situ inspection device. The main results are given here below (see also Fig. 5):

- Gamma spectrometry exams showed that the U deposits were mainly at the top of each diffuser and at the level of the barriers belt support structures (electrolytic nickel without thermal treatment, maximum of corrosion);
- The results are homogeneous: contamination is always at the same place in the different diffusion stages;
- After ClF_3 rinsing operations, a smoothing out of the radioactivity at the level of the barrier is noticed, with no more radioactivity peak;
- The highest efficiency is obtained using a dynamic ClF_3 rinsing operation;
- Up to 95% of the trapped U can be removed from the cascades.

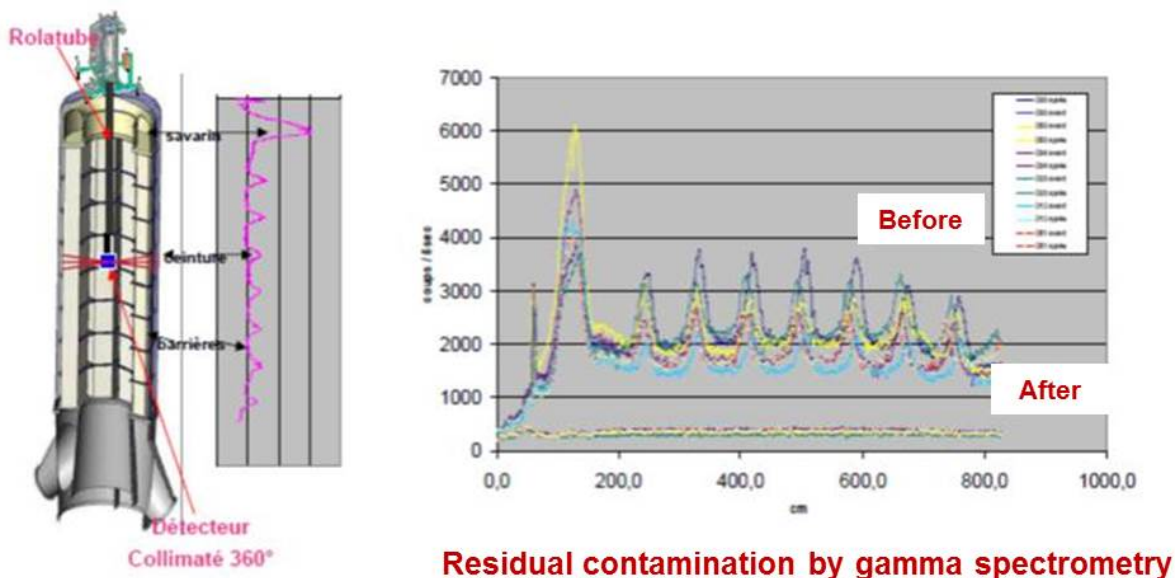


Fig. 5. Process system cleaning testing results

In addition of the ClF_3 rinsing operation, the use of humid air versus dry air to purge the cascades was considered. The purpose of the humid air treatment (called hydrolysis) is to extract and treat fluorinated and chloro-fluorinated components which have been generated during the ClF_3 rinsing operations. Hydrolysis averts chemical risks during subsequent dismantling operations and allows a controlled release of the reaction gases (HF , Cl_2 , gas filtration before discharging through the washing column). The cleanup by continuous air purge to reach HF (3 ppm) and Cl_2 (0.5 ppm) threshold will allow people to intervene without breathing apparatus.

A technical and economic analysis was performed to weigh costs and benefits of ClF_3 rinsing operation and further decontamination steps. In the end, the deactivation approach retained is based on a hot ClF_3 treatment followed by a hydrolysis treatment. It is a systematic approach where the main objective is always to secure the same end state allowing smooth subsequent dismantling operations.

Plant modification

During the deactivation phase, it is of vital importance to have all the process and control equipment operational and the qualified workforce able to use this equipment.

The ClF_3 rinsing operations require leak-proof cascades, minimum temperature, operating compressors and off gas treatment. So few modifications were done in the different facilities

ClF_3 facilities

Originally, the permanent use of ClF_3 in small quantities (5 metric tons a year) had been planned for the normal process operations. All the necessary installations were thus already operational with an onsite ClF_3 fabrication facility, a storage facility, discharge stations for introduction in the cascade, controls (analysis and measures) and a exhaust gas treatment facility.

The main difference in comparison to the production phase was the quantity used. So the ClF_3 facilities were subjected to maintenance and control operations.

Group temperature

During ClF_3 rinsing operations, compressor operations are short; there is consequently no permanent heat input. To avoid any risk of crystallization of the regenerated UF_6 , electric air heaters have been installed.

Hydrolysis and exhaust gas treatment units

Air introduction and extraction skids under controlled humidity have been installed on each building (see fig. 6). They have been designed for diverse operational modes of operation:

- Either to put the groups under very low pressure in order to facilitate the desorption of the HF gas trapped within the barriers and internal surfaces,
- Or to ensure an important ventilation flow to reach the final clean up level necessary for future dismantling operations (worker exposure limits: $[\text{HF}] < 3 \text{ ppm}$; $[\text{Cl}_2] < 0.5 \text{ ppm}$).

An extraction grid collects the air extracted from the different skids and sends it through a potassium carbonate (CO_3K_2) neutralization column before being rejected in the atmosphere.



Fig. 6. Humid air skid production

Operations

Industrial rinsing operations using ClF_3 started in June 2013. Skids and washing column tests are finished and hydrolysis and clean-up operations will start in November 2013.

By the end of October, 10 groups had been treated, and about 60 metric tons of UF_6 had been regenerated (40 metric tons of U). The quantities of Uranium recovered, in these preliminary results, have been generally more important than initially expected. These results are in the range of the high hypothesis estimate.

Some variability within the reaction kinetics has been observed, most likely due to the different chemical composition of the deposits (UF_4 , U_2F_9 , and UF_5) and to the different nature of the contact surfaces (massive or discrete deposits).

It is considered that the ClF_3 rinsing cycles are ended when the pressure increase between two compressor operations stays very low in the presence of a minimal quantity of ClF_3 .

That said it has been quite difficult to apply the shutdown standards mentioned above, particularly since the gas mixture is not perfectly homogeneous. In order to reach the level of precision of the mixture composition, it is necessary to have a very representative sampling of the gases as well as an accurate reading of the analysis tools. When the incertitude of the measurement is too great, an additional compressor rotation is done as to ensure the reactions are final.

DISMANTLING PROCESS EQUIPMENT

The four main steps of this phase of the GB1 D&D program are:

- Scenario definition and engineering studies (2012-2105),
- Licensing process (2016-2018),

- Capital expenditure (2019-2022),
- Dismantling operation (2023-2032).

After cleaning the cascade, the radiological assumptions on what the dismantling technical approach is based are:

- Maximum contamination of the barriers: < 50 Bq/g,
- Maximum contamination of metallic waste: < 15 Bq/g,
- Metallic waste non-fixed surface contamination between 4 Bq/cm² and 60 Bq/cm²,
- Total Uranium content is less than 20 metric tons.

The reference scenario is based on the process equipment removal, their dismantling and size reduction, the waste treatment and conditioning and the storage as a Very Low Level Waste (VLLW) at the ANDRA's CIRES repository site in the north east of France. For this purpose three different working areas will be created within the four process buildings of the GB1 plant (see fig. 7).

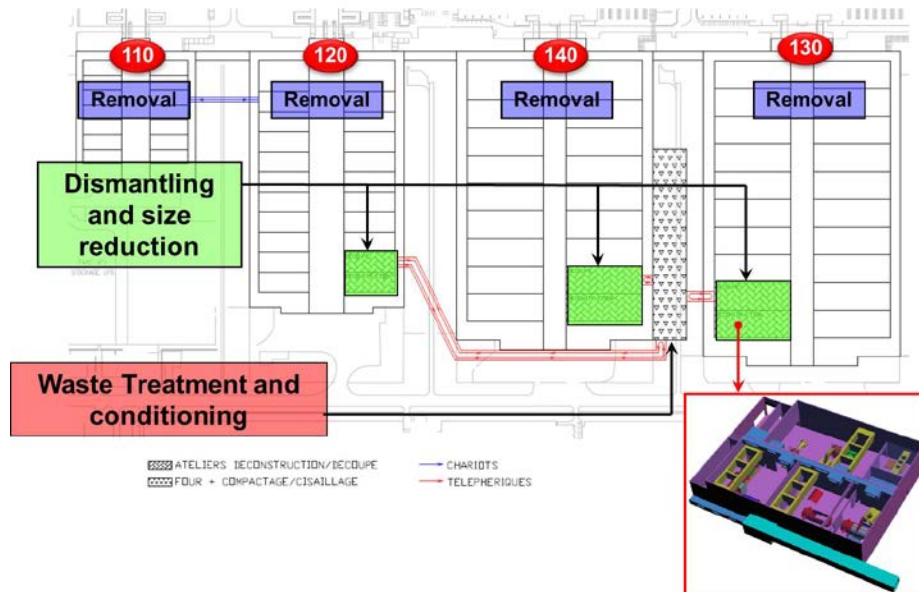


Fig. 7. Dismantling scenario – General layout

Process equipment removal

The approach consists of the removal of all the process equipment, mainly diffusion stages and piping, and their transfer to a dedicated unit for subsequent dismantling operations.

After the removal of the piping, the diffusion stages will be removed and tipped over in a horizontal position before the transfer to the dismantling and size reduction unit using a trolley.

Dismantling and size reduction

For each diffusion stage, the diffuser, the compressor and the exchanger will be first disassembled. Then

the barrier will be removed from the diffuser, crushed, grinded and packaged in waste boxes. The metal components will be cut in large pieces using different tools (i.e. disk grinder, plasma torch and shear) and transferred to the waste treatment area.

Waste treatment and conditioning

Three main functions will be carried out in this workshop: metallic waste treatment, waste packaging and waste interim storage before shipment to the VLLW disposal site.

The main process equipment will be a Super compactor, a 2,200 metric ton industrial shearing machine. It's compacting press and shredder equipment able to reduce the size and the volume of diffuser shells and process piping.

Similar equipment was successfully used to reduce the size of the metallic equipment of the UDG military Plant. It was an 800 Metric ton standard industrial compacting press installed in a nuclearized building (see Fig. 8)



Fig. 8. The super compactor used for the dismantling of the UDG military plant

CLEANING BUILDING

Even if most part of the plant is free from nuclear contamination, few areas are lightly contaminated; especially the part in the cascade where UF_6 was introduced or extracted to fill up cylinders.

Once all the process equipment will have been removed, these areas will be decontaminated using civil work decontamination technologies (i.e. concrete scabbling).

CONCLUSION

After successfully dismantling the first GDP dedicated to military applications, today AREVA is in charge of the decontamination and dismantling of the first commercial GDP in France (GB1 plant). Following an intense characterization and testing program, ClF_3 rinsing parameters of the GB1 cascade have been defined. Today, they are being successfully applied to simplify the dismantling of process equipment and to reduce waste management costs. AREVA has consequently acquired a unique know how of ClF_3 rinsing operations as well as operations of uranium recovery within a GDP.

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