Recent sodium technology development for the decommissioning of the RAPSODIE and SUPERPHENIX reactors and the management of sodium wastes

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ABSTRACT

This paper is presenting several processes recently developed and/or experimented by CEA in support to the decommissioning of two French Liquid Metal Fast reactors : RAPSODIE and SUPERPHENIX and also for the treatment of CEA sodium wastes.

1. INTRODUCTION

With the final shutdown of several Liquid Metal Fast Reactors (LMFRs) in France (RAPSODIE in 1982 and SUPERPHENIX in 1998) and abroad, appears the need of developing specific technologies belonging to the decommissioning field but that must be compatible with sodium handling. It can be said that the final shutdown of LMFRs has induced the emergence of a new aspect of sodium technology, closely linked with waste treatment and decommissioning operation. The aim of this paper is to present significant processes that has been developed at CEA and had after an industrial application.

2. PROCESSES DEVELOPED FOR THE RAPSODIE DECOMMISSIONING

RAPSODIE reactor definitively stopped in October 1982. At that time, several processes were developed to solve specific decommissioning difficulties. As far as possible and in most cases, it has been tried to extrapolate some process developed in normal operation to decommissioning application (i.e. cleaning process – see § 2.1.). But in other cases, the specificity of decommissioning of LMFRs was too important, and R&D studies must have been developed to achieve the goal. The best example remains the development of the NOAH process to treat the primary sodium of RAPSODIE.

2.1. Extrapolation of cleaning processes

In normal operation, sodium must be removed from every component extracted from the reactor which has been in contact with sodium. Indeed, it is estimated that the residual sodium layer thickness can be up to 30 µm on the vertical walls, and from 0.5 to 1 mm on the horizontal drainable surfaces. Therefore, every LMFR has several cleaning installations (called cleaning pits), to allow the treatment of all removable components from the reactor [1]. In cleaning pits, sodium is progressively neutralised by the contact of a mist made of a mixture of droplets of demineralised water and carbon dioxide. The chemical reaction of sodium and water mist is the following:

$$Na_{solid} + H_2O_{in\ excess} \Rightarrow NaOH_{aqueous} + \frac{1}{2} H_2 + heat$$

Aqueous sodium hydroxide produced by this reaction is then transformed to sodium carbonate in contact with carbon dioxide. Hydrogen is released in the ventilation duct after filtration and dilution. During all the chemical reaction, the cleaning pit is kept under inert gas (carbon dioxide or nitrogen). The process is controlled by adjusting the density of water in the mist in function of the concentration of hydrogen released from the cleaning pit before dilution. In normal operation, this percentage of hydrogen is lower than 1 %.

All the components used in RAPSODIE reactor (i.e. primary pumps, intermediate heat exchangers,…) were drained, removed, and cleaned in the cleaning pit devoted to the cleaning of components. Moreover some specific baskets were designed in order to put inside metallic wastes covered with sodium coming from decommissioning operations. Therefore the RAPSODIE cleaning pits have intensively participated to the treatment of all the structures with remaining sodium or covered by a film of sodium. In parallel, a cleaning pit was specifically devoted to the cleaning of all assemblies constituting the RAPSODIE core : fuel elements, breeders elements, control rods, steel elements. The defuelling was made in two campaigns. All the fuel, breeder elements and control rods were removed and cleaned from April to November 1983 (see Figure 1). The other elements (metallic assemblies) were removed later. The 468 reflector assemblies constituting the core (222 made of nickel, 246 made of steel) were highly irradiated. They represented, in 1987, a global activity of about 4500 TBq. In 1987 it was decided to take all the reflectors out and to store them at Cadarache site awaiting treatment before sending them to final repository. The operation of retrieving the reflectors from the vessel, washing them to eliminate traces of sodium, and installing them in a storage container lasted two years and required a workforce of 860 men per day with a production of 72 containers [2].

2.2. Caesium purification

One of the major contaminants of the primary sodium is caesium (^{133}Cs (stable), ^{134}Cs (half life: 2.06 y), and ^{137}Cs (half life: 30 y)). Caesium is a fission product principally released during fuel clad failures. These clad failures can be incidental in power reactors, or voluntarily induced for specific studies on research reactors. This radioisotope is therefore responsible for a significant activity (gamma emitter) during operation and also during dismantling phases (1 g ^{137}Cs represents 3.21 TBq), even at very low concentration in sodium (10^{-8}g of Cs/g of Na). Moreover, caesium is very soluble in sodium and is also very volatile: It can be found in the cover gas with high enrichment factors (100 to 400 in sodium aerosols). Experiments have shown that carbon and carbonaceous material (e.g. grease) have efficient caesium trapping properties. Specific purification processes of sodium from caesium have been developed to facilitate further handling and treatment of primary sodium or wastes coming from primary circuit. These studies were intensively developed in the 80's. They were applied to purify the primary sodium of RAPSODIE reactor where caesium traps were designed. Caesium traps are made with Reticulated Vitreous Carbon material (R.V.C.) which is a rigid, non graphitizable carbon foam, with a honeycomb-type cellular structure of very low apparent density. R.V.C. gives an excellent resistance to liquid sodium and its implementation as a trapping device entails no difficulties. Operating conditions are a trapping temperature monitored between 180°C and 300°C, with several mm/s sodium velocity within the trap. The efficiency of this type of trap allows a factor ten reduction in ^{137}Cs activity. With this process, primary sodium of RAPSODIE was purified in 1985 by around 1.85 10^{12}Bq of ^{137}Cs (42 kBq/g to 5.8 kBq/g) before being treated. The main advantage of this caesium purification campaign was that no specific radiological protection was necessary on the primary sodium treatment facility : the dose rate in contact of the facility was low enough.

2.3. Treatment of large volume of sodium : the NOAH process – the DESORA facility

For the treatment of primary sodium and in anticipation of the RAPSODIE decommissioning operations, CEA developed a process called "NOAH process", in order to continuously transform sodium in sodium hydroxide [3]. The principle of NOAH process consists in injecting small quantities of liquid sodium by a dosing pump through a sodium nozzle into a strong flow of aqueous sodium hydroxide (concentration of 10 mol/L) flowing within a closed vessel. The liquid sodium is scattered in the water and reacts smoothly and continuously. The chemical reaction being exothermic, it requires a continuous cooling through a liquid/liquid heat exchanger. The hydrogen produced by the chemical reaction is filtered, dried and diluted before release to the stack. The aqueous sodium hydroxide concentration is monitored and adjusted by adding water. The pilot facility to validate the NOAH process was developed by CEA between 1985 and 1989. Then the design of the DESORA facility (DEstruction du SOdium de RApsodie) started in 1989 and was carried out by Framatome (Figure 2). Sodium treatment by the DESORA facility started in 1994 and allowed the treatment of the 37 tons of primary sodium in three months (nominal flow rate of 40 kg/h). The treatment of the 37 tons of sodium produced around 180 m^3 of concentrated sodium hydroxide which was used to neutralise radioactive acidic effluents at La Hague reprocessing facility. It was the first time that a such volume of active sodium was safely and continuously treated.

3. PROCESSES DEVELOPED FOR THE SUPERPHENIX DECOMMISSIONING

When the decision was taken by the government to definitively stop the SUPERPHENIX reactor, no preliminary study on the decommissioning strategy was done. But at that time (in 1998), the RAPSODIE reactor had already achieved the main steps of the decommissioning operation except the primary vessel. Of course the experimental feedback of the RAPSODIE decommissioning was of great interest to develop a decommissioning strategy for SUPERPHENIX. The best illustration lies in the use of the NOAH process (see § 3.1.). Nevertheless, the change of size between these two reactors and also the change of concept (loop type versus pool type reactor) implies new difficulties that were not grasped on the RAPSODIE decommissioning project. Amongst these difficulties, one of the most significant is the sodium retention drilling (see § 3.2.). Moreover, SUPERPHENIX has decided to achieve quickly the decommissioning operation, including the primary vessel. Therefore EDF asked CEA to develop process to treat the residual sodium inside the main vessel by a carbonation process (see § 3.3.).

3.1. Treatment of the primary and secondary sodium of SUPERPHENIX : TNa facility

The reuse of the primary and secondary sodium for nuclear operation was not possible due to the absence of building of new LMFR in the near future. Thus the transformation of metallic sodium to a non reactive material becomes obliged. To do so, it was decided to use the reference "NOAH process" that will transform metallic sodium to concentrated sodium hydroxide (10 mol/liter). The treatment of primary sodium (3300 tons) and secondary sodium (1500 tons) will produce large amount of sodium hydroxide (19,000 tons). The facility envisaged will be based on the concept of the NOAH process, and on the design of the SDP facility (Sodium Disposal Plant) built to treat the primary and secondary sodium of PFR. It must be explicit that between the end of the treatment of the RAPSODIE primary sodium (1994), and the decision of the SUPERPHENIX final shutdown (1998), FRAMATOME associated with the NNC Company was chosen by UKAEA in 1995 to apply the NOAH process on a new facility called SDP (Sodium Disposal Plant, flowrate of 120 kg/h), designed for the treatment of the 1500 tons of primary and secondary sodium of the PFR reactor (Dounreay - Scotland) [4]. Therefore the experimental feedback of the DESORA campaign and the operation on the SDP facility are a good basis to prepare the future treatment of SUPERPHENIX's sodium. The project facility called TNa, will have a treatment flow rate of 6 metric tons per day. Sodium hydroxide will be transformed to cement before conditioning under the form of concrete blocks to be stored on site as Very Low Radioactive Waste. The treatment process should last 3.5 years from mid 2006 until 2009.

3.2. Sodium retentions drilling [5]

The total amount of sodium of reactor circuits is about 5500 tons, 3300 of them being in the primary vessel. About 99% of primary sodium could be easily pumped out of the main vessel. Thus, the remaining 1%, that is to say about 37 tons of sodium, mainly trapped in three zones (see figure 3) :

- 11.6 m^3 are trapped in the core catcher which is made of two large piled plates,
- 12.2 m^3 are trapped in the lower part of the core diagrid,
- 8.6 m^3 are trapped at the bottom of the main reactor vessel itself.

A first study was performed in 1998 in order to select the processes which existed and were convenient to drain these three zones of trapped sodium. At that very first step, twenty-five processes were proposed by FRAMATOME and the CEA : drilling, sawing, TIG or beam cutting, detonating, pumping, siphon during main draining, electro-erosion, laser cutting, high pressure fluid cutting, chemical attack, ultrasound waving, punching, gas ejecting... After taking into account the specific conditions of SUPERPHENIX (geometry, chemical and temperature conditions), the mechanical drilling process was selected and considered more closely. Only the core catcher drilling is described hereafter (sodium trapped in the lower part of the core diagrid will be siphoned and sodium trapped at the bottom of the main reactor vessel will be pumped). Mechanical drilling was finally selected, as it is the most well known process with a considerable worldwide proven behaviour. Nevertheless, the long distance between the roof slab (above which the motorization has to be positioned) and the drilling zone - twenty meters deeper – leads to a significant technical challenge.

a. Drilling tests at room temperature with conventional drilling machine

The core catcher is made of two large stainless steel piled plates (∅8 m). In order to drill through them, another upper structure within the reactor block, which is thicker (30 mm) than the core catcher plates themselves (20 mm) must be drilled first. The whole drilling scenario then consists of three phases :

- 1. drilling the thicker plate :	∅50 mm diameter hole,
- 2. drilling the upper core catcher plate :	∅26 mm diameter hole,
- 3. drilling the lower core catcher plate :	∅12 mm diameter hole.

Before performing tests under realistic conditions (piled plates, 180°C temperature, liquid sodium, argon atmosphere, flexible machine), it was decided to perform some tests using a conventional drilling machine in order to check the efficiency of selected conventional tools (twist drills made of high speed steel material), to select convenient drilling conditions (stability, cutting and feed speeds, without any cooling lubricants), to measure mechanical load and tool overheating, to try to recover chips, to estimate the local atmosphere effect (air, argon or nitrogen).

b. Drilling tests under realistic conditions, with a prototype drilling machine

A prototype drilling machine was designed by FRAMATOME and manufactured by NNS (a FRAMATOME subsidiary) on the basis of the results obtained at room temperature (feed and cutting speeds, mechanical loads, chip recovery), and of the SUPERPHENIX plant context (flexibility of the drilling machine due to the long distance between the drilling zone and the motorization, under liquid sodium drilling, limited size of available access). It is only 4.32 m high thanks to a short specific device simulating the mechanical behaviour of the real 20 meter long machine (same flexibility in rotation and in compression), built on four strong feet (see figure 4). The drilling machine and the test pot were under argon atmosphere (+ 50 hPa) and isothermally heated (tests are performed at 180°C). A series of realistic drilling tests have been performed in 2000 at CEA/Cadarache (34 tests). They were in anticipation of the drilling operations scheduled on the SUPERPHENIX site in 2002-2003.

By these tests, the following drilling scenario was confirmed :

1. drilling the thicker plate : ∅50 mm diameter hole,
2. drilling the upper core catcher plate : ∅26 mm diameter hole,
3. drilling the lower core catcher plate : ∅12 mm diameter hole.

Moreover it has been demonstrated that, the chip recovery was good as with a conventional drilling machine : some chips do fall after opening the drilled hole and when the tool is removed. These results were considered as good enough to allow the design of the actual drilling machine to be finalized : sodium will be drained off (the main goal of the drilling operation), the dimensions of the actual machine were defined, some margins were taken for tool damage. As a secondary requirement, chip recovery is rather complete. Drilling procedures have been assessed for each of the four drilling operations ; the operator can face any mechanical and remote control problem.

c. Application on SPX

In 2002 and 2003 the facility was tested on SUPERPHENIX site, first on air, then under water conditions. At last, in October 2003, the ∅50 mm drilling hole and the ∅26 mm drilling hole were successfully done in the primary vessel.

3.2. Carbonation process to be used on the primary vessel [6]

When the volume and/or geometry of a sodium-wetted component do not permit its transfer into a cleaning pit, it is then necessary to realise an in-situ treatment of the remaining sodium. Such a process is necessary for large components such as Steam Generator modules or for sodium vessels (such as the SUPERPHENIX spent fuel storage vessel). By means of this treatment, the risks linked to the presence of metallic sodium are reduced or completely eliminated. Therefore, safety of the decommissioning period will be enhanced, and further dismantling operations will be eased. The process used in France consists in injecting inside the component to be treated a circulation gas carrying a very low amount of water : the gas must be kept at room temperature, under the saturation point in water. The circulation gas is a mixture of carbon dioxide and nitrogen. Therefore in contact with the humidity carried out by gas, sodium is smoothly reacting, producing anhydrous sodium hydroxide which will then be transformed to solid sodium bicarbonate ($NaHCO_3$) in contact with CO_2 gas. The concentration of water in gas must be kept low to avoid the hydration of sodium hydroxide. Thus, the whole chemical reactions are giving solid products avoiding uncontrollable reaction due to liquid spillage on metallic sodium. Moreover, by keeping a very low concentration of water, hydrogen is continuously limited to a very low level (measured in ppm).

This process has already been applied with success by FRAMATOME for the internal cleaning of the spent fuel storage vessel of SUPERPHENIX in 1988 before its dismantling. In that case the objective was to neutralise sodium films in large areas, localised thicker retention areas being then removed by mechanical means. In 1998, EDF asked CEA to start kinetic studies on the carbonation process in order to treat not only films of sodium but also deep bulk of sodium always keeping safe conditions. From 1998 until the end of 1999, a specific facility was designed and implemented at CEA/Cadarache. It is called CARNAC and offers the possibility to test simultaneously four different operating conditions. From 2000 to 03, several carbonation tests were made to define the best parameters to use, to treat thick bulk of sodium.

The study of the sodium carbonation reaction has been conducted in three main steps :

- A first step to determine the optimal area for the different parameters in term of reaction rate. For this step it was chosen to test carbonation process during 100 hours on small bulk of sodium (cylinder of 20 cm of diameter and 1 cm thick).
- A second step to determine the maximum efficiency of the process in chosen operating conditions after analysis of the first results. These experiments will be done on thick samples of sodium (until 10 cm thick) and with a reaction duration of 1 to 4 months in accordance with the progress of the reaction.

- The last step define the behaviour of the optimised process in specific or extreme situation (i.e. loss of gas circulation).

a. Results of the first step

In the first step each parameter has a large range of variation because the aim was to feature the kinetic of the reaction in a large area of operating conditions which can be encountered at the industrial scale. The variation range of each parameter was the following :

- For water fraction in the gas : from 0.3 molar % to 5.9 molar %,
- For carbon dioxide fraction in gas : from 0 molar % to 40 molar %,
- For gas flowrate : from 50 to 1000 L/h which corresponds to a reactor renewal from 0,1/hour to 2 /hour.
- For gas temperature : from 21 to 59°C.

All these experiments have been done during a minimum of 100 hours. No limitation of kinetic have been observed. On the other hand, the reaction rates are very dissimilar from on experiment to another one. This two observations can be easily explained. In fact when the reaction is fast, the formed carbonate layer is very thick but a lot of cracks appears and allows to continue the reaction without slowing down. The maximum of thickness we have treated is about 7 mm in 100 hours (Figure 5).

b. Results of second and third steps

Long duration carbonation tests were made during over four months long. It appears that there was no significant kinetic limitation mainly due to sodium carbonate that expands, cracks everywhere and therefore creates new crevices where humid gas can continue the carbonation process (see Figure 6). Consequently, the carbonation process appears to be a very efficient and safe process even for sodium bulks. After this main conclusion, EDF engineering division decided to choose this process to treat the residual amount of sodium let in the primary vessel after sodium draining. The carbonation process was also selected as a pre-treatment process on secondary loops before their decommissioning.

4. PROCESSES DEVELOPED FOR SODIUM WASTE TREATMENT [7]

The final shutdown of the SUPERPHENIX reactor was accompanied by a general cleansing of the CEA support sodium facilities and also a strategy treatment of old sodium wastes still stored on several CEA sites. This general strategy involved development of new specific processes devoted to treat different sodium wastes type. Three principal process were developed : an autoclave reactor to treat small amount of highly active sodium or sodium/potassium alloy, a large cleaning enclosure to treat mixed wastes (sodium plus steel), and the development a several cutting tools validated to cut efficiently and safely sodium wastes.

4.1. The Autoclave reactor

This process concerns the treatment of highly active sodium or NaK, with an important activity (components or irradiation devices in which fuel failures have been provoked, caesium traps,…). Therefore the facility is put in a hot cell and can be handled by telemanipulators. The principle of the process consists in the following steps :

- Wastes are cut by a reciprocating saw, in order to obtain metallic elements melt with sodium.
- Constitution of wastes baskets with a maximum of 500 g of sodium.
- Treatment by autoclave reactor. The aim of this process is to realise a sodium/water reaction using a limited volume of sodium and a water excess. This reaction is achieved in an autoclave reactor studied to support the fast raise of pressure and temperature due to the water/sodium reaction (Figure 7).
- When these two parameters (pressure and temperature) are stabilised, the reactor is decompressed and the hydrogen produced is diluted after treatment (stripping, drying, filtration) in a inert gas flow.

The process has already been successfully used to treat more than one hundred bottles filled with active NaK alloy coming from SILOE experimental irradiation reactor. The maximum quantity held in one bottle was 500 grams.

4.2. The Active Cleaning Enclosure facility

This facility has been designed to treat large volume of active sodium mixed with other wastes (metallic structures coming from decommissioning operations, or old sodium waste stored in tanks). Before the treatment phase, an important preparation phase is necessary :

- preparation of the wastes : opening of the containment, disassembling of the inactive accessories,
- introduction into an active cut cell,
- cut of the wastes with a reciprocating saw (pipes, valves) and a band saw (large tanks, cold traps). After the cut, the sodium into the wastes must be accessible.
- constitution of baskets with a 0.5 m width capacity and containing until 1 tonne of sodium. The baskets must be designed so that the sodium is accessible by the treatment process.

- intermediate storage of the basket before washing.
- washing of the baskets in the active cleaning enclosure facility.

This process developed in the cleaning active enclosure facility, consist in making a chemical reaction with sodium by water atomisation in an nitrogen flow (see Figure 8). Injection by nozzles allows a local cooling and permits an intensive chemical gas sweeping in the reaction area. The water flow injection can be increased to reach the sodium in the top of the basket. Injection by the bottom make easier the hydroxide sodium evacuation. A recycling device cools the containment atmosphere. This kind of facility has already been used to treat large volume of inactive oxidised sodium coming from sodium fire experiments. A new facility is now under study to treat active wastes.

4.3. Development of cutting techniques of sodium wastes [8]

It was decided to test the cutting techniques with industrial machine on specific components that can sum up all the sodium wastes. These specific components were : a storage vessel with a residual puddle of solid sodium at the bottom, a cold trap full of sodium, a sodium valve and several sodium pipes (different diameters). Tests were done at CEA/Cadarache centre on non active components. Finally, the tests have concluded that four cutting techniques could deal with all kind of sodium wastes : band saw, reciprocating saw, nibbling machine and hydraulic shears.

a. Band saw

Band saws were found to be able to cut all kinds of structures associated with sodium waste eg. cold traps with internals, metallic mesh, massive sodium valves etc. No difficulty was experienced when performing several cuts on a cold trap full of sodium and on a drum half-full of sodium (Figure 9). The process has demonstrated both toughness and reliability. This technique did not result in melting of sodium but only generated swarf made up of a mixture of steel and sodium. For cutting large diameters (a diameter of 1500 mm has been tested) a minimal lubrication of a few ccs of oil has been necessary.

b. Reciprocating saw

When cutting components with a maximum diameter of 450 mm, including those components full of sodium, Reciprocating Saws were found to perform well in these trials. It was noted that sodium stuck to the blade and there was a slight melting of sodium in the cutting area. However, no ignition of sodium was observed. It was also noted that sometimes it was necessary to lubricate (with oil) the blade to ease the cutting operation. The likelihood of the blade getting stuck in the component is very slight. Therefore, this technique would appear to be very robust, tough and reliable. The major drawback of this cutting technique is that a diameter of 800 mm seems to be the upper limit of component volume that can be cut. Moreover, the cutting machine is relatively massive (Figure 10). Due to its good performances, reciprocating saw has therefore been selected to cut small components (diameter lower than 800 mm) such as pipes, small cold traps, valves...

c. Nibbling machine

Nibblers has shown their efficiency for the cutting of component with an internal residual film of sodium such as emptied sodium storage vessels or pipes (Figure 11). The use of the Nibbling Machine is a well established cutting technique. It has been selected to cut large components that have been drained of sodium. Nibbling machines can also be used as a cutting technique to support other techniques as in the case of blockages or other difficulties.

d. Hydraulic shears

This technique was tested on tubes of 32 mm to 50 mm of diameter full of sodium. This technique works well but it was noticed an important extrusion of sodium when the pipe is full of sodium, like toothpaste in a tube (Figure 12). This technology can be used for the cutting of tubes (full or emptied of sodium), for the cutting of drained component and as a help in case of problems or difficulties (blades blocked in sodium for example).

e. General conclusions on cutting techniques

The four cutting techniques presented, i.e. band saw, reciprocating saw, nibbling machine and hydraulic shears, has proven their efficiency to cut sodium wastes under severe conditions : cutting done on large components, under air, and with a minimum of lubrication. Thus, these cutting techniques are recommended for sodium waste treatment and also in the frame of the general decommissioning of Liquid Metal Fast Reactors (LMFRs) cooled with sodium (the large majority of LMFRs built in the world).

5. CONCLUSIONS

Decommissioning LMFR's involves the safe application of novel and demanding technologies. It is therefore incumbent on the relevant organisations to ensure that adequate expert review is carried out. As operations of the reactors are run down, the relevant knowledge needs to be retained into the decommissioning phase. If there is a significant delay before decommissioning starts, vital experience and knowledge can be lost. The important experience gained by CEA by developing these several processes has been valorised by the involvement as recognized sodium expert in different national and international decommissioning projects : SUPERPHENIX decommissioning, SILOE cleansing [9], PFR and DFR reactors decommissioning (Great Britain), sodium and NaK wastes coming from MOL (Belgium).

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Figure 1 : Endoscopic view of the inlet of the RAPSODIE reactor when the fuel and breeder elements were removed (July 1987)

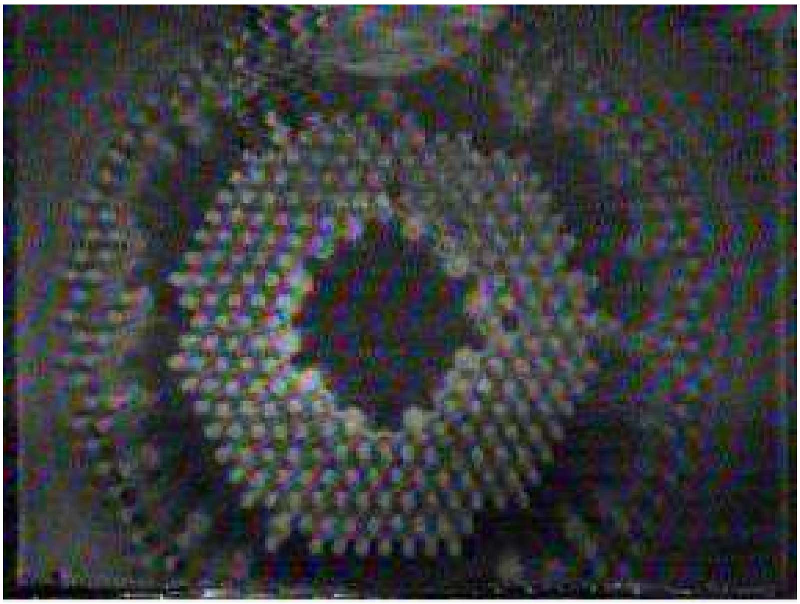

Figure 2 : Cut view of the DESORA FACILITY

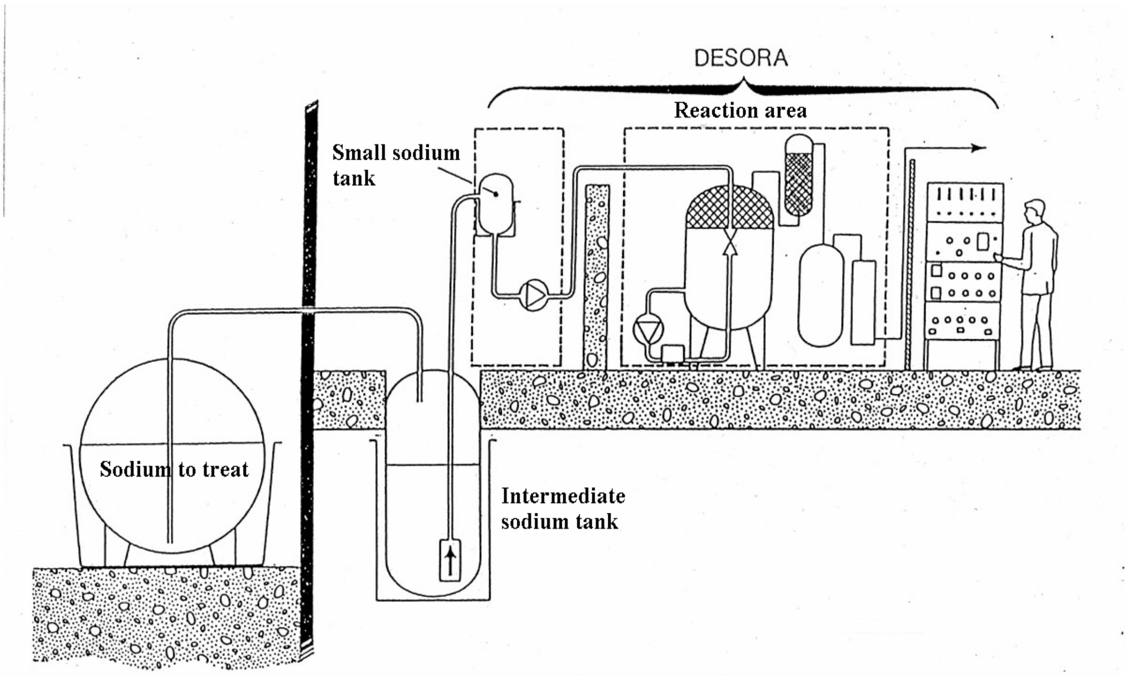

Figure 3 : Core catcher geometry

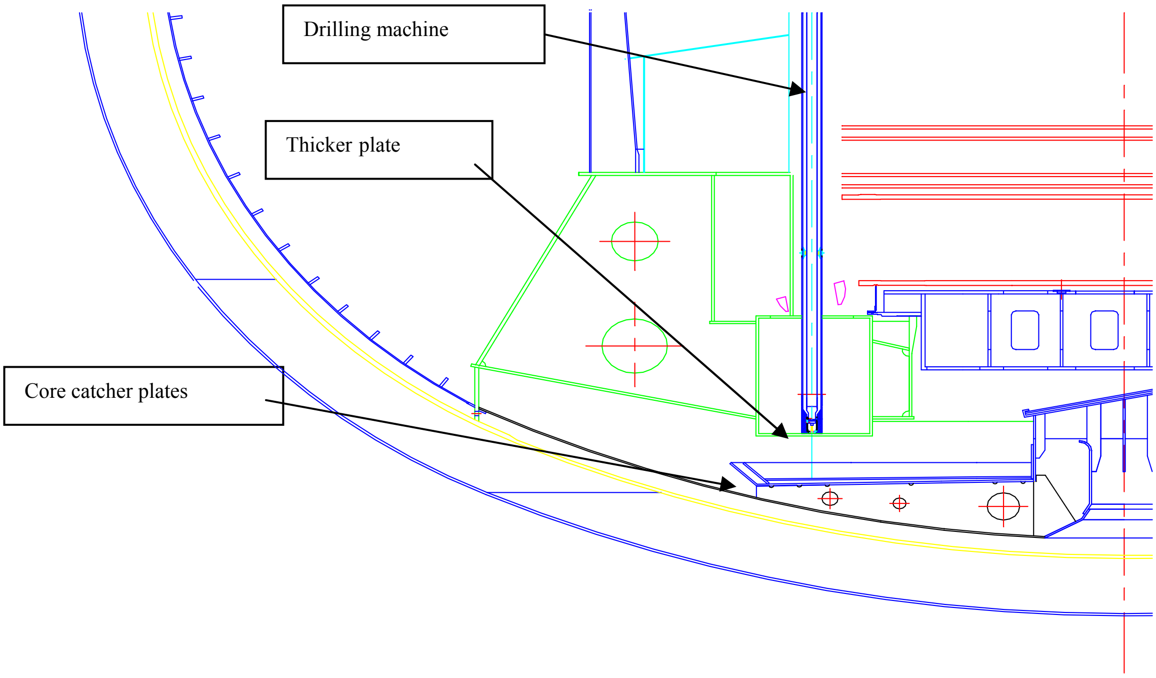

Figure 4 : Prototype drilling machine at CEA/Cadarache

Figure 5 : Formation of sodium carbonate (step 1)

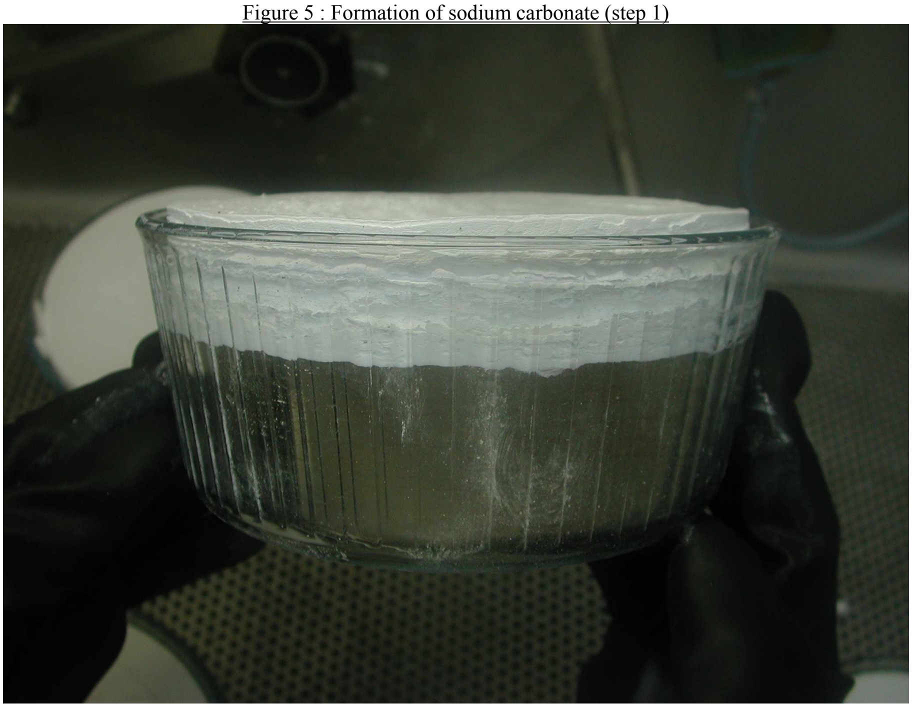

Figure 6 : Formation of sodium carbonate (step 2)

Figure 7 : Design of an autoclave reactor in a hot cell

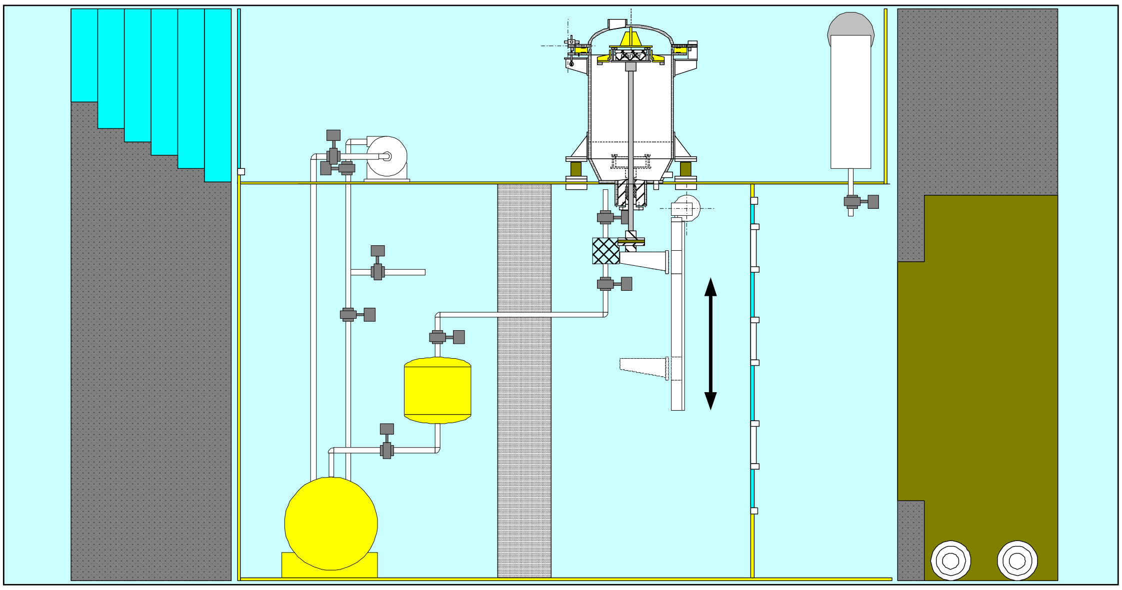

Figure 8 : Design of the Active Cleaning Enclosure

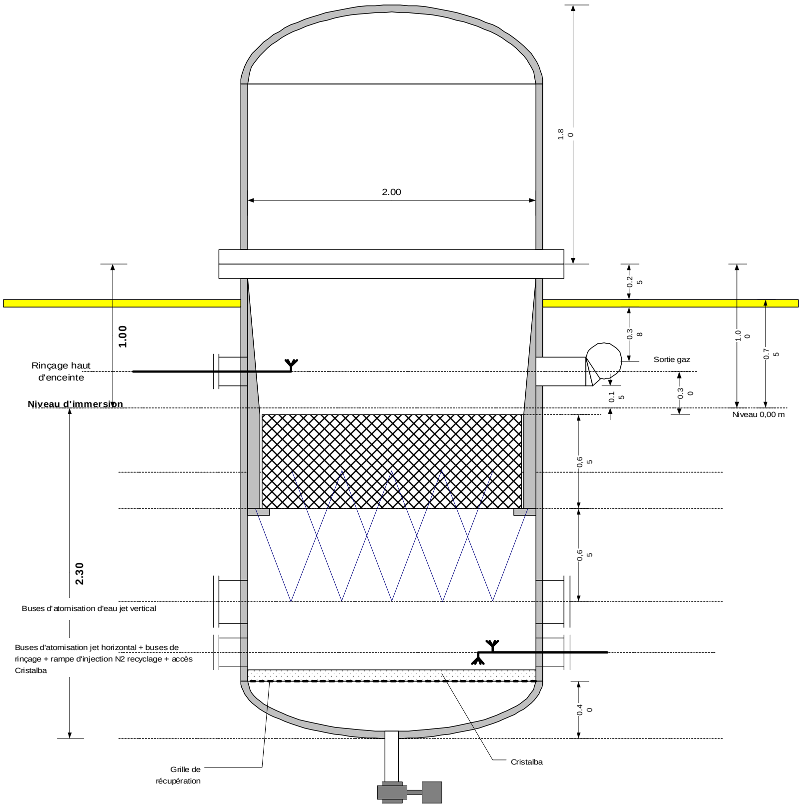

Figure 9 : Slice of cold trap full of sodium cut with a band saw

Figure 10 : The reciprocating saw cutting a cold trap

Figure 11 : Pipe with residual sodium inside being cut in its length by a nibbling machine

Figure 12 : Tubes full of sodium being cut with hydraulic shears