40 YEARS OF EXPERIENCE IN INCINERATION OF RADIOACTIVE WASTE IN BELGIUM

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ABSTRACT

Since the very beginning of the nuclear activities in Belgium, the incineration of radioactive waste was chosen as a suitable technique for achieving an optimal volume reduction of the produced waste quantities; several R&D projects were realised in this specific field and different facilities were erected and operated.

An experimental furnace “Evence Coppée” has been built in 1960 for treatment of LLW produced by the Belgian Research Centre (SCK.CEN).
Regularly this furnace has been modified, improved and equipped with additional installations to obtain better combustion conditions and a more efficient gas cleaning system.

Based on the 35 years experience gained by the operation of the “Evence Coppée”, a completely new industrial incineration installation has been designed in the nineties and commissioned in May 1995, in the frame of the erection of the Belgian Centralised Treatment/Conditioning Facility CILVA.
At the end of 1998, the new furnace has burnt 455 tons of solid waste and 246 tons of liquid waste.

Beside the conventional incineration process, a High Temperature Slagging Incinerator (HTSI) has been developed, constructed and operated for 10 years in the past. This installation was the combination of an incinerator and a melter producing melted granulated material instead of ashes, and provided experience in the incineration of hazardous waste, such as chlorinated organic compounds and waste with PCB content.

The paper presents “the Belgian Experience” accumulated year after year with the design and the operation of the here above mentioned facilities and demonstrates how the needs required today for a modern installation are met.

The paper covers the following aspects:

- Design particularities and description of the systems
- Operational results for different solid waste categories (bulk waste, precompacted waste, ion exchange resins) and for different liquid waste categories (organic, aqueous, oil)
- Required pretreatment of the waste
- Ashes conditioning: R&D activities performed in this field
- Improvements made to solve specific problems
- Public acceptance of incineration.

BELGATOM is a nuclear and consulting engineering company, providing a wide spectrum of nuclear services, among other in radwaste management, in Belgium and abroad.
BELGOPROCESS, a company set up in 1984 at Dessel (Belgium) where a number of nuclear facilities were already installed, is specialised in the processing of radioactive waste. It is a subsidiary company of ONDRAF/NIRAS, the Belgian Nuclear Waste Management Agency. According to its mission statement, the activities of BELGOPROCESS focus on three areas :

- treatment, conditioning and interim storage of radioactive waste,
- decommissioning of shut-down nuclear facilities and cleaning of contaminated buildings and land,
- operating of storage sites for conditioned radioactive waste.

INTRODUCTION

Belgium has started its nuclear R&D-programme in 1955 within the Belgian Nuclear Research Centre. From the very first beginning special focus was given to the problem of radioactive waste treatment. Incineration of wastes was chosen as a promising technique for reaching optimal volume reduction. An experimental furnace has been built in 1960 for treatment of LLW produced by the research centre. Regularly this furnace has been modified and equipped with supplementary installations to obtain better combustion conditions and a more efficient gas cleaning system.

Aiming to obtain a better final combustion product suitable for disposal without further conditioning a new incinerator concept was developed based on a common melting technique. The HTSI (high temperature slagging incinerator) is the combination of an incinerator and a melter producing melted granulate material instead of ashes. In 1974 the first prototype was constructed, upgraded in 1980 to a semi-industrial plant, used for the incineration of low level alpha bearing wastes. This plant was shut down in 1988.

Test campaigns for the incineration of hazardous waste were performed in the HTSI plant. Highly chlorinated organic compounds and PCB-containing wastes have been efficiently incinerated with very low noxious gases emission levels.

In 1989, ONDRAF/NIRAS decided to build on the BELGOPROCESS site, a new centralised facility, the CILVA Facility, for β and γ low-level and α-suspect waste produced in Belgium. This facility is based on a 2000 ton supercompaction installation and a 120 kg/h incineration plant for solid and liquid radioactive waste. It also comprises a reception, storage and distribution unit for the waste packages, a routing installation, a pre-treatment installation, a decontamination station and a conditioning unit. The latter is meant to immobilise supercompacted pellets or special incombustible and incompressible waste prepared in the pre-treatment installation. Furthermore an active mixer is installed for embedding of wet waste like ion exchange resins or sludge, should the need arise.

BELGATOM performed the Architect Engineering activities for the whole facility.
BELGOPROCESS started the plant operation in June 1994 (first radioactive waste supercompaction) and May 1995 (first radioactive waste incineration).

DESIGN PARTICULARITIES AND DESCRIPTION OF THE SYSTEMS

EVENCE COPPEE FURNACE INITIAL DESIGN

The Evence Coppée furnace, built in 1960, consisted of a first chamber for the incineration of lignite (material used for ion exchange treatment for low level liquid effluents) and ion exchange resins, a second chamber for ordinary wastes followed by a post-combustion chamber.

The combustion gases were cooled down by air dilution and then filtered through a battery of heat-resistant prefilters and absolute filters.

Combustion of PVC, polyethylene and rubber gave rise to carbon black which rapidly blocked the filters.
The use of a coke-bed on a horizontal grid in the second combustion chamber as an in-furnace carbon black filter was one of the novel pioneer ideas for a better control. Alternative flue gas cleaning systems were later on tested:

- use of movable prefilter to protect fixed pre-filters
- application of electro-filtration after wet conditioning of the flue gas resulting in clustering of submicron soot particles

EVENCE COPPEE ADAPTED DESIGN

After a few years of operation, the waste feeding and the off-gas treatment systems were modified in order to allow the incineration of higher contaminated waste, i.e. for β-γ wastes packages with a contact exposure rate up to 2 m Gy/h.
The maximum quantity of β-γ emitters was limited to 37 GBq/m^3 and for the α-emitters, other than 226 Ra and transuranics, to 37 MBq/m^3. The waste included bulk waste packed in 15 litre bags precompacted to a specific weight of maximum 300 kg/m^3, powder and granular resins, burnable prefilters and HEPA filters, animal carcasses and small vials with residual quantities of organic liquids.

The presorted waste packages were conveyed to the furnace inlet by a set of belts. Feeding both primary combustion chambers was done in parallel through a set of air locks. The incinerator was kept at an underpressure of 5 to 10 mm WG by two extraction fans. Both combustion chambers were equipped with an inclined cast metal grid with upstream combustion air throughput. The thermal capacity of the furnace amounted to 580 kW. The wastes were burned out at a temperature of 900 to 1000 °C. Underneath the grids, slightly preheated combustion air was injected in both chambers (see Figure 1). In both combustion chambers an automatic supporting propane burner with a power of 300 kW was installed to maintain the preset operating temperature.

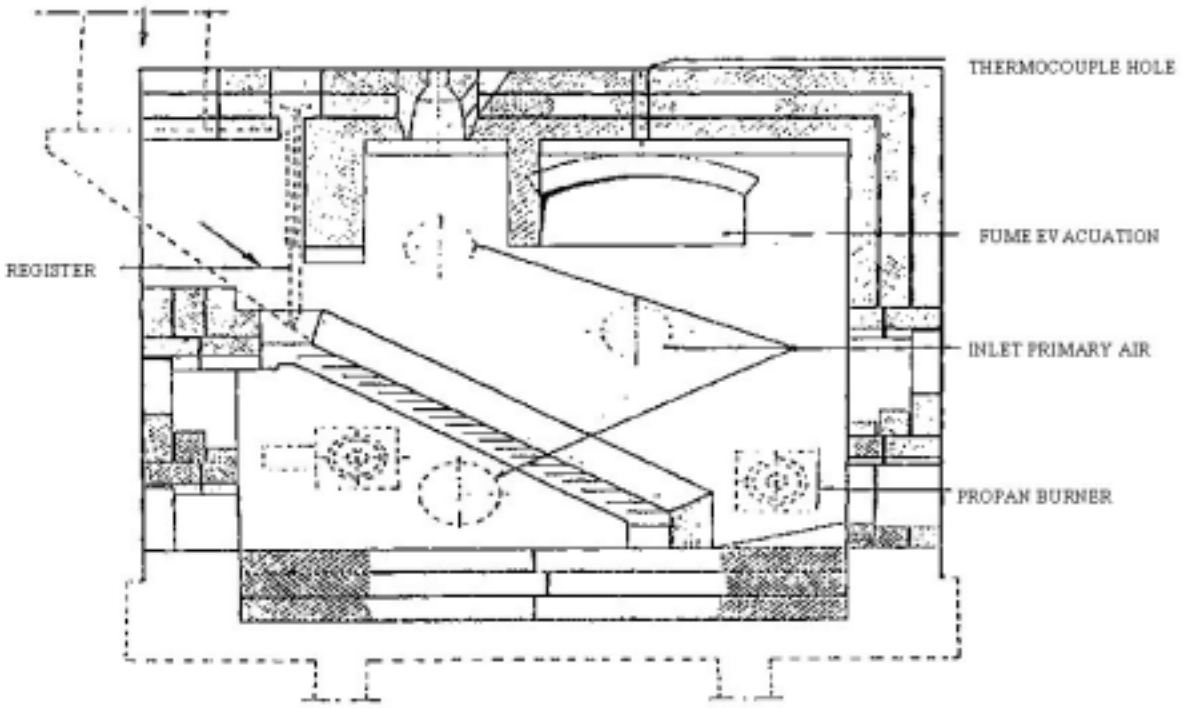

Fig. 1 : EVENCE COPPEE SYSTEM MODIFICATION - GRILL ARRANGEMENT

In order to allow the combustion of liquid waste, an injection system was installed. It consisted of a pressure drum, a feeding line and an injection lance. Collection bottles were emptied and fed under nitrogen pressure.

Control of the liquid injection system was independent from the furnace control for solid waste. This very simple installation has been used for many years without major operational problems. Blocking of the transfer line was the major inconvenience of the system, making frequent cleaning necessary which has to be done manually. In 1984, after a burn outside the furnace which caused partial damage of the transfer line and injection lance, the system has been disconnected.

After modification of the LLW furnace in 1990, the furnace has again been equipped with an installation, licensed in 1992, for the injection of liquid wastes. Small aliquots of organic liquids

or mixtures of aqueous and organic liquids, collected in 30 l bottles were being injected into the primary combustion chambers by nitrogen pressure. In-line filters prevented the transfer line from blockage. The liquid was atomised in the head of the injection lance by compressed air. The lance itself was heat protected by cooling with water. Oil collected in higher volume containers was pumped to separate lances in the post combustion chamber. The total operating capacity was about 30 l/h for organic liquids from bottles and about 10 l/h for oil.

Off-gas purification was done in three phases : cooling, dust removal and scrubbing. After passage through the heat recuperator for preheating the combustion air, the evacuated off-gases were further cooled down to approximately 240 °C by water injection. The off-gases were dedusted in the venturi washer in close contact with the caustic water. The liquid mist was coagulated in a spray tower. The particle removal efficiency of the venturi scrubber under working conditions and a pressure drop of 750 mm WG was about 97 % for 0,3 μm particles. The dedusted off-gases were further cleaned from corrosive components, such as HCL and SO2, by counter-current scrubbing in a column filled with Rashig rings, followed by a static drop separator. The temperature of the dedusted and scrubbed off-gases approached 40 °C. Evacuation of the off-gases was done by two parallel coupled two-stage fans of 90 kW. Their net extraction capacity reached 3000 Nm^3/h under 1050 mm WG. The sludge loaded scrubbing water was treated by coagulation and separation in the nearby waste water treatment plant.

DEVELOPMENT OF THE HTSI-TECHNOLOGY

In the beginning of the seventies SCK/CEN began the development of the High Temperature Slagging Incinerator (HTSI). The HTSI was meant to be an integrated system which directly converts mixtures of combustible and non-combustible radioactive wastes as well as sludges into a stable leach-resistant residue suitable for safe disposal.

In the HTSI-plant (see Figure 2) the shredded solid waste mixture was introduced into the ring chamber of the primary combustion chamber by means of a set of screw conveyors. In this chamber a rotary distributor pushed the waste into the lower part of the combustion chamber where it formed an inverted cone. The upper part of the combustion chamber had a bell shape. It was lined with ceramic material and contained the main burner which initiated and controlled the combustion. The lower layer of the waste inverted cone was heated up to its melting point (about 1500 °C) by thermal radiation reflected by the walls of the bell chamber from the burner and the burning waste. Droplets of the molten slag layer flowed down the cone to the slag outlet nozzle. Combustion air was injected into the bell and through the waste cone. Since the combustion gas could only be discharged through the slag outlet nozzle, it first passed through the slag layer which acted as a liquid filter and retained most of the dust. It then entered the combustion chamber and finally flowed through the outlet nozzle. After passage through the outlet nozzle, the molten slag droplets were separated from the combustion gas and dropped into the granulator located underneath the nozzle. The combustion gas was channelled into the horizontal post-combustion chamber. An auxiliary burner, installed opposite the post-combustion chamber, maintained the temperature of the outlet chamber at about 1300 °C in order to keep the slag liquid and to allow full combustion of the gas.

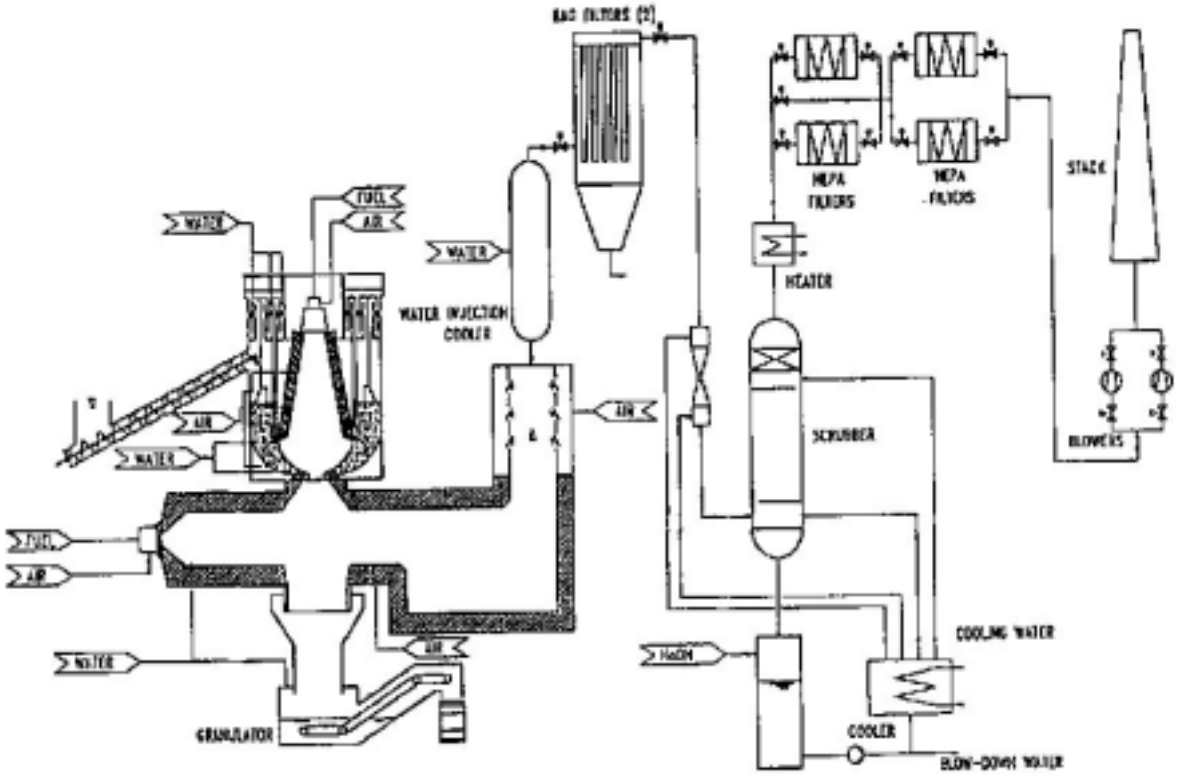

Fig 2 : HTSI SCHEMATIC FLOW DIAGRAM

The process objective of the HTSI off-gas treatment line was the removal of semi-volatile and volatile radioactive components and other noxious gases, such as SO2 and HCl. The off-gases left the post-combustion chamber at 1000 °C and were cooled down to 800 °C by addition of fresh air. The gases were further cooled to 200 °C by direct atomising of water in a cooling tower. This allowed the cooled gases to be filtered through bag filters, in order to reduce their dust content to less than 2 mg/Nm3. The dust collected on the filter elements was removed by pulses of compressed air, and collected in hoppers. The filtered off-gases were further scrubbed with alkaline solution in a venturi scrubber and a wash tower. After re-heating to a temperature of 80 °C, the purified gases passed through three batteries of HEPA filters. The off-gas ventilator kept the overall system in under pressure and extracted the off-gases.

THE CILVA INCINERATION SYSTEM

Waste characteristics

The CILVA incinerator has been designed to treat the following types of radioactive waste :

- uncompacted and shredded/compacted solid waste such as clothing, gloves, rags, cotton, rubber and plastics (PVC quantity 3 % average, caloric value of about 25 MJ/Kg)
- frozen animal carcasses
- ion exchange resins (caloric value of about 20 MJ/kg)
- organic liquid waste such as scintillation liquids and organic solvents (caloric value of about 35 MJ/kg)
- aqueous liquid waste whether or not containing organic components and solid particles
- spent oil (caloric value of about 40 MJ/kg).

Based on a weekly operation time of 100 h the designed capacity is 10 ton/week of solid waste, besides 1 to 3 ton of liquid wastes. The required burn-out of the ashes is min. 95 %. The radioactivity limit of the waste is 40 GBq/m^3 for beta-gamma emitters and 40 MBq/m^3 for alpha emitters, with a maximum dose rate at the surface of each package of 2 mSv/h.

Process description

The overall schematic flow diagram is given in Figure 3.

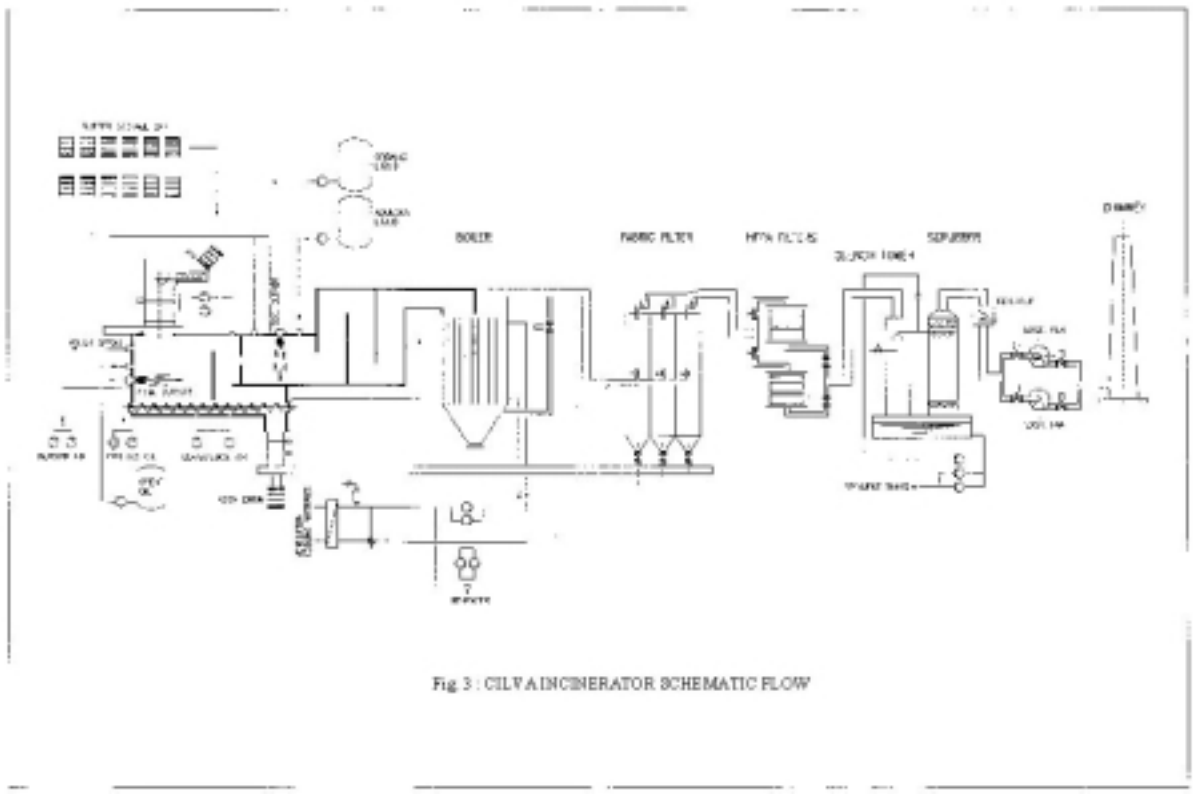

Fig 3 : CILVA INCINERATOR SCHEMATIC FLOW

The solid and liquid waste transport packages are stored in the warehouse. In the solid waste pre-treatment line, the primary waste package are controlled (dose rate measurement, weight, absence of metallic parts) before being transferred into incinerator feed containers which provide 24 hours buffer capacity. These feed containers, hanged to an overhead conveyor, are automatically transferred to theincinerator. The solid waste is fed to the incinerator via two locks. The first lock is the glove box from where the waste is automatically transferred via a vibrating table to the second lock, comprising two successive slide doors connected to the incinerator. The two locks create a double barrier between ambient atmosphere and the primary combustion chamber. The organic and aqueous liquids and the spent oil are transferred to special storage and incinerator feed tanks. From there the liquids are directly pumped to the injection lances.

Primary Combustion Chamber (PCC)

The radioactive waste undergoes a combined process of combustion and pyrolysis. The PCC operates at a specific temperature range of 900 °C to 950 °C.
An automatic water spray is used to limit high temperature excursions of the combustion gases.
The primary burner operates with gas oil and is sized to accommodate the thermal load during weekly startup. During the combustion cycle the burner can run from low to high fire. With the typical high energetic waste the burner is normally shut off.

In the ash bed of the PCC two augers are turning forward and backward to obtain high combustion burnout residues through sufficient residence time and good contact with combustion air. Cold air is forced through the hollow shaft of the augers to cool them and to protect them from over-temperature. The heated air is mixed with the off gases at the entrance of the boiler. At the bottom of the PCC the ash, with a temperature of about 70 °C, falls into a hopper from where it is discharged via two sliding doors into a 200 litre drum. Fly-ash from the boiler and the bag filter is transferred by means of a vibrating tube to the same drum.

Secondary Combustion Chamber (SCC)

The unburned gases and soot particles entering the SCC are mixed with excess air to complete oxidation of primary components such as CO_2, SO_2, HCl.
The excess air supply is regulated by an oxygen analyser-regulator at the outlet of the SCC. The set point is 8 % O_2. Due to the special shape of the SCC there is an intense mixing between unburned gases and excess air creating high turbulence. This process gives a combustion efficiency higher than 99,9 %.
The SCC is sized to provide a minimum of two seconds residence time at the design waste feed rate and at a temperature of 1050 °C.
The secondary burner operates with gas oil and modulates between high and low fire as function of the outlet temperature of the SCC.

Waste Heat Boiler

The combustion gases leaving the SCC are cooled down to 200 °C into the three-pass hot water boiler. The hot water is circulating in a closed circuit and the waste heat is transferred to the exhaust ventilation air of the CILVA facility via cooling batteries.
Before the winter of 1996, a heat recuperation system was installed, recuperating 500 kW for heating the CILVA building. In the recuperation circuit an intermediate heat exchanger has been built in between the controlled area and non-controlled area.

Flue Gas Purification

The bag house consists of 3 compartments with 45 filter bags per compartment. Two compartments are in service while one is in standby. This provides an approximate air-to-cloth design ratio of 0.9 m/min.
The capture of particulate matter is done by surface filtration of membrane filter bags consisting of a microporous expanded PTFE membrane laminated to a PTFE fiberglass fabric. The bags can withstand operating temperatures of 260 °C. The cleaning of the filter media is done on line by means of pulsed jets of compressed air triggered by a differential pressure switch. The collected particulates are shaken off the surface of the bags.
The hopper at the bottom of the bag house receives the released particulate matter and emptying is accomplished through a rotary discharge valve to the vibrating tube.

After the fabric filters the gases enter the HEPA filters consisting of two parallel compartments. One compartment is in standby. The outlet temperature is 170 °C.

The wet gas scrubbing assembly consists of a quench tower for cooling down the gases to about 50 °C, a countercurrent scrubbing tower with caustic liquid for removal of HCl and SO_2 and a demister.
The flue gases are heated up with 5 °C to decrease the relative humidity and to avoid condensation.

Two extraction fans in parallel ensure the evacuation of the flue gases to the atmosphere. The negative pressure is controlled through a motor-driven valve placed at the suction end of each extraction fan.

OPERATIONAL RESULTS

EVENCE COPPEE FURNACE (1960-1995)

The incinerator was used to burn the radioactive waste produced at the Belgian Nuclear Research Centre. It consists of a rich variety of laboratory waste containing small concentrations of several radioisotopes.

Small aliquots of liquid waste were produced as well. Only LLW was incinerated. Burnable ILW and HLW have been treated otherwise.

From 1973 onwards, NPP's were put in operation in Belgium and the radioactive waste produced was treated by the Nuclear Research Centre at Mol. Burnable waste was incinerated in the Evence Coppée furnace.

LLW from many other waste producers was treated by the Nuclear Research Centre as well. Waste was delivered by research labs, hospitals, universities, chemical and pharmaceutical industry…

Up to 1990 the operational results were as follows. The operation regime of the furnace was 100 hours a week, from Monday till Friday. After each two-week period, an extra intervention was carried out in view of removing the not routinely eliminated ashes from the incinerator. The feeding rate was about 90 kg/h. The mass reduction factor for normal burnable waste was about 10, for resins 30 to 35. The bulk density of the ashes was 360 to 400 kg/m^3. The volume reduction factor therefore reached from 10 to 70. The carbon content of the ashes amounted to > 3 % for resins, and to a few % with a maximum of 35 % for other waste types. In the gas purification line a specific quantity of soot of 0.025 to 0.035 kg/kg burnable waste was obtained. This secondary waste was conditioned with bitumen.

The LLW furnace has been operated under these conditions for more than 15 years treating a yearly waste quantity of about 300 tons.
After modification in 1990 the overall combustion performance was much better. The mass reduction factor mounted up to 20 for ordinary waste and up to 35 for resins. The mean volume reduction factor for a mixture of waste was 55. The carbon content of the ashes was < 1 %.

HTSI (1974-1988)

The history of the HTSI developing experiments is as follows:

- 1974-1977: non active preliminary tests
- 1978-1979: tests on β-wastes
- 1980-1988: tests on α-wastes; treatment of β and α-wastes; treatment of liquid wastes.
- 1988: shutdown of the installation

The main advantage of the HTSI-technology compared to low temperature incineration was the production of stable granulate material instead of ashes. The properties of the granules for a typical feed composition were as follows:

- grain size distribution (x) > 5 mm 21 wt %
- 2.5 < x < 5 mm 27 wt %
- 2.0 < x < 2.5 mm 13 wt %
- 1.0 < x < 2.0 mm 26 wt %
- 0.5 < x < 1.0 mm 8 wt %
- < 0.5 mm 5 wt %
- bulk density: about 1,500 kg/m^3
- true density: about 3,300 kg/m^3
- micro harness: 500 10^7 N/m2 (5 GPa)
- microstructure: amorphous matrix, basalt like appearance
- main constituents: silica, alumina, ferrous oxides, alkaline earth oxides, …
- global leaching rate: Soxhlet leaching rate based on most significant elements: 10^{-5} tot 10^{-4} g/cm^2.day
- melting point: about 1,200 °C.

Although suitable for direct final disposal, R&D work has been performed to further increase the volume reduction by densification of granules by hot-pressing at about 800 °C and 320 MPa. Under these conditions, monolithic solids with outstanding compressive strength (445 MPa) were produced with an additional volume reduction factor of 1.9. A final density of 3.6 and a micro-hardness of 5.9 to 6.3 GPa is obtained. Resistance to leaching was increased by the densification step and was comparable with that of bitumen and some glass products.

INCINERATION OF LIQUID HAZARDOUS WASTES

In 1996, the HTSI plant was licensed for the incineration of liquid hazardous non-radioactive waste.

A wide range of liquid wastes from the chemical process industry has been incinerated. High viscous, highly chlorinated liquids, containing residues of heavy metals have been incinerated. The maximum chlorine concentration in the feed was about 60 %. At regular intervals the efficiency of the incineration and off-gas cleaning process has been evaluated. The process was controlled by measuring residual off-gas concentrations of typical unburned constituents of the feed steam, concentration of PCDD and PCDF in the off-gases, concentration of combustion

products (NOx, SO_2, HCl), and by measuring or calculating overall process parameters (O2-content in the off-gases, temperatures, flow rates, underpressure, residence times).

Typical combustion efficiency values were > 99.5 to 99.99 % at temperatures between 800 °C to 1200 °C, residence times of 0.5 to 2 seconds, and lambda values of 1.5 to 3. Under normal operating conditions total PCDD and PCDF-concentrations were below detection limits. When detected PCDD and PCDF values at the outlet of the combustion chamber reached up to a few hundred mg PCDD and a few ten mg PCDF per litre of waste incinerated. Especially H7CDD, OCDD, H7CDF and OCDF were detected with minor concentrations of H6CDD, H6CDF, PCDD and PCDF. Including the high efficient flue gas treatment line (combined cooling, filtration and wet scrubbing) the overall process efficiency was always higher than 99.99 %.

CILVA

Table I illustrates the average emissions of a typical campaign burning 3 % PVC, 20 % resins, polyethylene, polypropylene and cellulose. All results show lower achieved emissions values compared to those allowed. Observe the low particulate matter content due to the high filtration efficiency of the bag filters. The HEPA filters have been changed once only since the start up.

TABLE I
Chemical emissions

	Allowable (1)	Typical off-gas composition
Particulates	100 mg/Nm^3	< 1 mg/Nm^3 (2)
CO	100 mg/Nm^3	5 mg/Nm^3
NO_X	400 mg/Nm^3	88 mg/Nm^3
SO_2	300 mg/Nm^3	25 mg/Nm^3
HCl	100 mg/Nm^3	18 mg/Nm^3
HF	4 mg/Nm^3	< 0,1 mg/Nm^3 (2)
TOC (3)	20 mg/Nm^3	0,2 mg/Nm^3
Values corrected to 11 % oxygen and dry gas (1) Local region-incinerators with capacity of less than 3 ton/h (2) < detection limit (3) Total Organic Carbon		

TABLE II
Chemical and radiological composition of effluent

	Specification "Very Low Level Waste"	Achieved average
• alpha	40 Bq/l	< 1 Bq/l
• beta-gamma (Co-60 equivalent)	400 Bq/l	25 Bq/l
Co-58		< 1 Bq/l
Co-60		< 1 Bq/l
Sb-125		< 1 Bq/l
Zn-65		< 1,6 Bq/l
Cs-134		< 0,9 Bq/l
Cs-137		< 1,3 Bq/l
I-125		45 Bq
H-3		9000 Bq/l
• Cl	200 mg/l	167 mg/l
• S	300 mg/l	50 mg/l
• suspended particles	100 mg/l	2 mg/l
Zn		< 0,07 mg/l
Sb		< 0,3 mg/l
Na		173 mg/l
Ca		45 mg/l
• pH	6-9	7,5
< detection limit		

The chemical composition and radioactivity of the effluent (see table II) are within the specification for "LLW" imposed by the general water treatment plant of the BELGOPROCESS site from where it is rejected into the river after additional treatment and final characterisation. The radioactivity of the typical volatile Cs-isotopes is lower than the detection limits, which proves that almost all radioactivity is captured before the fabric filter collector.
The gaseous isotopes such as I-125 and tritium are washed out from the flue gases.
The radioactivity discharge in the stack exhaust is near the background radioactivity and far below the licensed values respectively 0,1 % for alpha emitters and 0,001 % for beta emitters.

From the active start-up in May 1995 to the end of 1998, the incineration plant has been operated during some 6873 hours and treated 455.6 ton of solid waste, 246.3 tons of liquid waste leading to an average incineration throughput of 102 kg/h. The average incineration throughput for 1997 and for 1998 was respectively 127 kg/h and 118.5 kg/h.

REQUIRED PRE-TREATMENT OF WASTES

Pre-treatment of waste is necessary prior to incineration. The extent of pre-treatment is influenced by the type of incineration used, and the way the wastes are delivered.

EVENCE COPPEE

The waste feeding system originally consisted mainly of a sorting glove box placed above the inlet opening of the combustion chambers. Not burnable parts were sorted out and collected in drums for separate processing. Although simply conceived direct sorting of waste before incineration was a time consuming process step. The direct connection with the hot furnace environment created safety problems and burning risks outside the furnace in the sorting box. Fire in the sorting box indeed has happened.

After redesign and simplifying the pre-treatment line, direct waste input through an air tight water cooled lock was applied. This was only practicable after special arrangements taken with waste producers to sort and specially pack different waste streams separately.

HTSI

Size reduction of the waste was necessary and performed by a shredder. The shredded waste was fed to the HTSI-incinerator through screw conveyors. Sorting of waste was not specifically requested since unburnable materials were allowed to be fed into the furnace; only protection of the shredder against metallic pieces was requested.

Liquid waste incineration

Liquid waste was injected into the furnace under Nitrogen-pressure. To obtain high destruction, effective atomisation of liquid waste was necessary. To prevent blockage of nozzles and pipes, filtration of liquid waste was mandatory.

CILVA

The CILVA incinerator is equipped with two ash extraction screws. Blockage and damage of the screws are prevented by eliminating all metal parts. Detection of metal parts is done by X-ray assay. Sorting of detected unsuitable packages is done manually in a glove box. Acceptable waste packages criteria are specified and imposed onto the waste producers, preventing many manual interventions in the pre-treatment line.

CILVA INCINERATOR ASH CONDITIONING

CONDITIONING METHOD

Ashes and dust from the boiler and the baghouse filters are collected in 200 litre drums for further supercompaction in the supercompaction unit of the CILVA Facility. Corresponding

supercompacted drums are placed in 400 litre overpacks and transferred to the Conditioning Unit where they are immobilised by means of a cement matrix.

This conditioning method was selected after Research studies and experiments were conducted in the frame of the CILVA Facility Basic Design Phase.

Preliminary experiments were carried out on homogeneous solidification of ashes, with a poor burn-put, in a cementitious matrix. This method was swiftly discarded because of:

- unacceptable bleeding in most cases;
- hydrogen release during the matrix setting;
- low ash incorporation rate (maximum 15 to 20% weight of ashes in order to fulfil Belgian conditioned waste acceptance criteria).

Hence, it was decided to investigate the feasibility of ash compaction and encapsulation of the pellets. After that attempts of ash pellets in bitumen did not give satisfactory results (drum swelling), the use of cement matrix was investigated.

In 1990, a supercompaction campaign took place in Mol on the site of BELGOPROCESS, with a mobile unit. During this campaign, several trials were carried out, including the compaction of eighteen 200 l ash drums produced by the EVENCE COPPEE incinerator. Water was added in three ash drums to simulate the most stringent conditions to be expected. The pellets did not show any visible tear. The achieved height reduction factor allows to pill up 3 to 4 pellets in one 400 l drum, that is about 400 kg ashes.

Six 400 l drums have been produced, each one containing three pellets.

Two drums were sent to the “Bundesanstalt für Materialforschung und -Prüfung (BAM)” in Berlin for computerised tomography examination.

The four other drums were sealed up with a special lid in order to detect any pressure build up and to allow gas sampling. Twelve days after encapsulation, the highest pressure values were recorded for each drum: the values varied from 0.075 to 0.24 bar. A gas sample was taken from a drum and its analysis gave the following result:

TABLE III
Drum gas sample analysis

Element	H_2	N_2	O_2	CO_2	CH_4	Ar
% in Volume	35.4	62.7	0.9	0.02	0.035	0.7

The hydrogen release was attributed to the oxidation of metal fines. According to literature, aluminium is the cause. However, the non-conditioned waste specification precludes aluminium metal in the combustible materials.

The rapid fall of oxygen content due to the use of blast furnace slag cement should also be noted; this phenomenon restrains any aerobic corrosion process into the drums.

Moreover, neither during the pellets encapsulation nor later, was any evidence of gas release noticed (no bubbles, no cracking of the mortar surface).

Furthermore, examination of mortar samples from the drum that has given the highest gas production demonstrates that hydrogen formation has no significant effect on the setting and hardening of the matrix.

Parallel experiments were conducted in order to define the total hydrogen volume that could be produced by the ashes. Therefore, samples from the eighteen ash drums to be supercompacted were neutralised with concentrated NaOH solution: those measurements showed a maximum possible hydrogen production of about 1 Nm3 for the ash content (400 kg) of one overpack drum.

Finally, in order to simulate water intrusion during final disposal, water was added in three overpack drums. Only a slight increase in hydrogen production was reported.

The pressure build-up measurement's campaign lasted for about 9 months, until no additional gas production was observed.

MASS AND VOLUME REDUCTION FACTORS

Table IV gives the quantities of all radioactive waste incinerated, as well as the quantity of produced ash.

TABLE IV
Amounts of incinerated radwaste and ash production

Year	Incinerated radwaste (kg)			Ash (kg)	Weight Reduction Factor
	Solid	Liquid	Total		
1995	68 771	14 583	83 354	3 734	22
1996	139 591	89 049	228 640	8 652	26
1997	133 134	86 872	220 006	8 468	26
1998	114 104	55 807	169 911	5 797	29
TOTAL	455 600	246 311	701 911	26 651	26

A global Volume Reduction Factor (volume of raw Solid and Liquid waste/volume of conditioned waste) amounts to around 100.

IMPROVEMENTS MADE TO SOLVE SPECIFIC PROBLEMS

EVENCE COPPE FURNACE

In 1990 the inner refractory lining of the combustion chambers had to be replaced. At this occasion the furnace was redesigned to further increase combustion efficiency (see Figure 4). The redesigned incinerator still had two separate chambers and one common post combustion chamber. In opposition to the original design, the flue gases from chamber 1 and 2 were no longer mixed before they reach the common post combustion chamber. In this way it was possible to control combustion in each primary chamber individually. The existing grids in the two primary chambers were replaced with a ceramic combustion hearth, with controlled air supply. The combustion hearths were chosen being more suitable especially when incinerating waste with a high plastics content and a low ash content. Each combustion chamber had an apparatus for injection of atomised water for high limit temperature control. A new common post combustion chamber was constructed having two individually controller steps for supply of combustion air, in a manner that results in good mixing with the off-gases loaded with particles. The post combustion chamber was followed by a retention chamber, which gave the off-gases sufficient retention time to burn out in a turbulent flow pattern. At the entrance of the retention chamber a secondary oil burner was placed (830 kW) for maintaining a temperature of 900 to 1200°C for 0,6 to 1 second. The air supply was controlled by the oxygen content in the off-gases leaving the incinerator. Each primary combustion chamber had a new individually controlled primary gas oil burner (350 kW), placed in the wall opposite the waste feed. From a combustion air fan, air was supplied to a manifold. This windbox was provided with a number of outlet dampers, each damper having its own damper motor. Air was supplied to the front and rear part of each of the primary combustion chambers, as well as to the two sections in the post combustion chamber. The air supply to the various chambers was controlled by temperature, pressure, oxygen content in the off-gases, and waste feeding procedures.

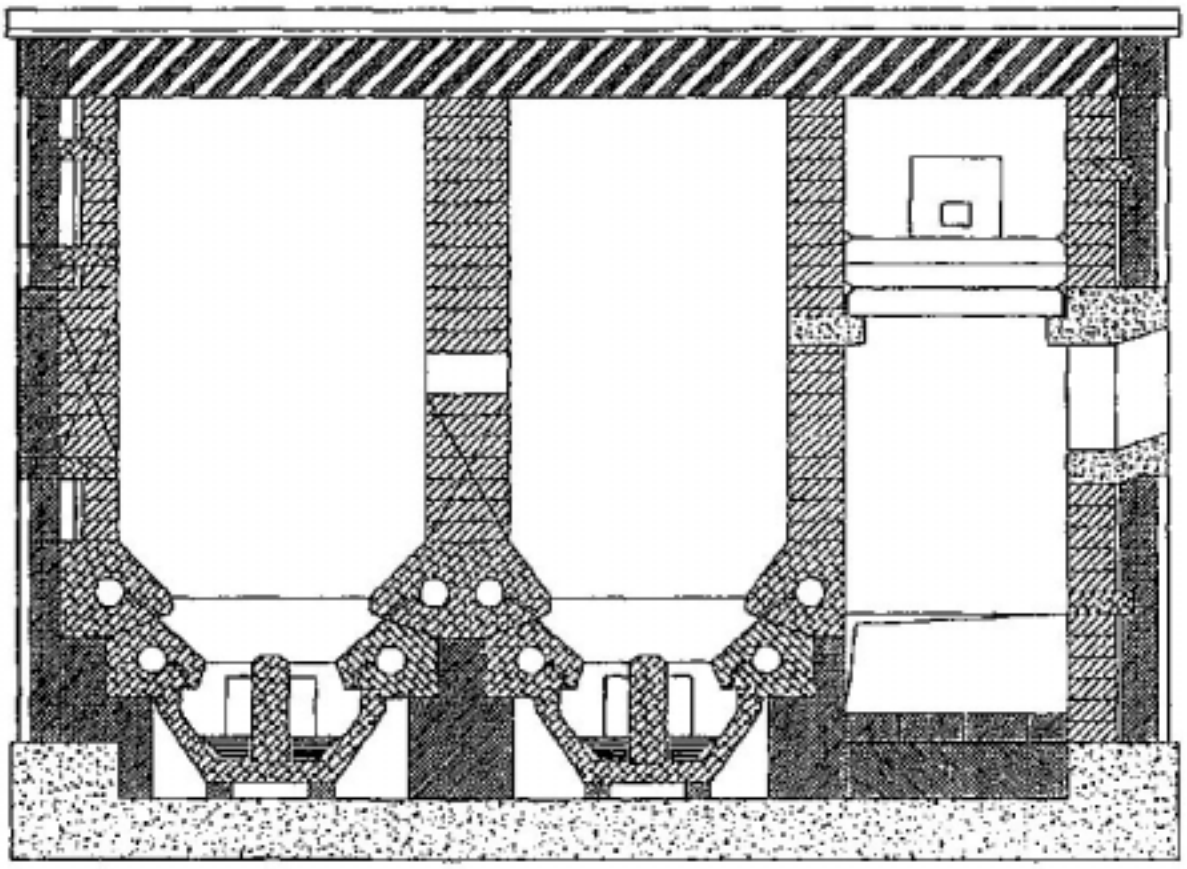

Fig 4 : EVENCE COPPEE FURNACE AS ADAPTED IN 1990

CILVA

Functional problems

Auger damages

The augers have a length of about 4 meters and are made of heat resistant stainless steel. After eight weeks of operation one of the screws broke into two pieces. The place of the rupture was at about 1,2 m from the burner wall. After investigation, the main reason for the breakage was inter-granular corrosion near the welds. Therefore we decided to install two new augers made of Inconel-625 that has a higher corrosion resistance and a higher limit temperature. A the same time the support structure of the drive transmission and main bearing, at the outside of the incinerator, was rebuilt to simplify the mounting, demounting of the assembly and alignment of the augers.

At the end of 1996 one of the augers broke again. The reason was combination of erosion and presence of metal pieces. The erosion caused by the ashes creates a thinner pipe thickness of the augers resulting in a lower resistance against rotating forces. The erosion was important over a length of about one meter before the furnace bridge. The last two meters were still in good

shape. So it was decided to cut out the bad piece and to weld in a new one of about 1,5 m. After alignment the auger was mounted again into the incinerator.
After the first operation period the following evaluation can be made: the advantage of augers is that ashes are automatically mixed up and transferred to the ash drum without manual operations. On the other hand following disadvantages can be noted:

- The augers are sensitive for metal pieces. This means that into the waste feed subsystem every package has to be checked and sorted out if metal pieces are present. Sorting out of the radioactive waste is done manually with protective clothes and masks. Sensibility campaigns have to be carried out convincing the waste producers to follow the waste specifications and to do a better separation of metal pieces in the burnable solid waste.
- A set of augers has to be on site as capital spare parts to limit operational down time after failure.
- Due to erosion caused by the ash, each year one set is replaced.

Taking into account this evaluation, the small capacity of the incinerator and the low ash content of the waste,
the operator recommendation for new plant is to install an alternative, for example a well-designed manual poker device. One manual intervention per shift is sufficient for raking up the ashes and transferring them to the ash drum. Additional advantages are the burn out of the ash can be controlled easily, manual intervention for sorting out the waste and repairs of the augers are not necessary anymore

Fabric Filter Collector

A certain period after start-up the differential pressure over the fabric filter became all the time 1700 Pa which caused a lot of automatically stops of the incinerator. Even after continuous pulsed jet cleaning cycles the situation did not improve.
After laboratory analyses of the fly-ash, collected from the surface of the bag filters, phosphorus was found as one of the main components. At operation temperature the phosphorus oxides stick up to the bag filters and clogged them up.
Further investigation showed that the phosphorus oxides mainly come from the phosphates, which are present in small concentrations into organic and aqueous liquid waste. As corrective actions a lime injection system was installed. Before taking into operation the new bag filters, a precoat of lime (calcium carbonate) is applied. During operation the aim is to add as less as possible lime because at the end it is transferred to the ash drum and decreases mass reduction factor. Due to the lime injection the differential pressure goes down after a cleaning cycle to the normal operation value of about 1000 Pa. Every 24 hours one or two cleaning cycles are necessary and during one week about 50 kg of lime is injected.

Underpressure Regulation

The normal underpressure in the PCC during operation is about 200 Pa and the controlling system has to compensate for variations in the flow of the flue gasses. These variations are due to adjustment of combustion air as function of the O_2 content, start up of a burner, begin of a

loading cycle.
The underpressure adjustment was initially carried out by the motor-driven valve, located upstream of the exhaust fan, which received pulse signals from the main PLC.
Most of the time, the underpressure was too high but sometimes, especially during a loading cycle, overpressure occurred and lasted for a few seconds. Adaptations into the PLC program have avoided the overpressure occurrence but smooth normal operating conditions were not reached.
Frequency regulators, for varying the motor speed of the extraction fans, were installed and allowed to succeed stabilising of the underpressure in the PCC.

Programme Logic Controller (PLC) system

The incineration system is controlled by a main PLC coupled with an emergency PLC. Twice there was a loss of PLC control resulting in a complete black out of the system, even the emergency PLC has not taken over the vital components. The operators have reacted promptly by resetting the main PLC by using the key of the control panel. The system returned to normal situation and vital parts started again. Possible reason was a communication error between the two PLC systems. Such events are unacceptable and parts of the main PLC programme were reprogrammed. The emergency PLC was completely reprogrammed and additionally a relay cabinet, with switches and indication lamps, was added to take over vital functions such as extraction fans, boiler pumps, auger fans and scrubber pump in case of failure of both PLC systems.
After the modification all alarms and emergency systems were tested again.
Since that time no failures occurred on the PLC systems anymore.

Liquid Waste Capacity Improvement

In the original design injection of spent oil into the PCC and the organic and aqueous liquid wastes into the SCC was foreseen. Because a lot of water was to be injected into the PCC for limiting the temperature increase, we decided to redesign the process. A higher capacity transfer pump for aqueous waste was installed and a new piping lay-out for the liquid waste feed lines around the incinerator was carried out. The PLC program was reprogrammed for additional process control. In function of the caloric value of the solid waste, the aqueous liquid waste and spent oil can now be injected as well into the PCC as into the SCC.
This modification has improved the flexibility in waste treatment strategy and has more than doubled the liquid waste capacity in normal process conditions.

Incineration capacity improvement

The improvements around the fabric filter collector, mainly, and the redesign of the liquid waste injection system, have led to increase, respectively, the solid and the liquid waste incineration capacity as shown on following table.

TABLE V

Capacity and burnout

	Before changes May '95---> end of Feb. '96	After changes June '96 ---> end of Dec. '96
Net capacity solid waste	59 kg/h	79 kg/h
Net capacity liquid waste	35 kg/h	61 kg/h
Burn-out of ash	85 %	85 %
Net capacity = total weight/(total available time - time start/stop - time for maintenance)		

PUBLIC ACCEPTANCE OF INCINERATION OF RADIOACTIVE WASTE

Incineration of radioactive waste is applied in Belgium since 1960. In those pioneering years, public involvement did not exist. Emphasis was put on technological development and improvements by technicians and engineers. The public was not aware of incineration being applied or didn't express any criticism. Since then 40 years have passed. At present the general public is rather well aware of social and technological issues. Environmental protection has become a key issue and a requirement for acceptance of technologies and processes. Incineration of waste in general has been characterised by emission of dioxins, soft and heavy metals. Causes of several diseases have been linked with waste incinerators. This trend is internationally perceived.

Incineration and thermal destruction of radioactive waste at Belgoprocess can still be applied and opposition is not very expressed.

This is caused by:

- the long term positive experience of applying incineration processes for radioactive waste treatment
- the use of modern up to date technology characterised by high destruction efficiency
- the very low even negligible environmental impact of incineration practices
- the Belgoprocess company communication strategy towards public and stakeholders, characterised by transparency and active information campaign.

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