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# CUTTING TECHNIQUES FOR FACILITIES DISMANTLING IN DECOMMISSIONING PROJECTS

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## ABSTRACT

Fuel cycle related activities were accomplished in IPEN-CNEN/SP in laboratory and pilot plant scale and most facilities were built in the 70-80 years. Nevertheless, radical changes of the Brazilian nuclear policy in the beginning of 90's determined the interruption of several fuel cycle activities and facilities shutdown. Some laboratory and pilot plant decommissioning activities have been performed in IPEN in the last years. During the operational activities in the decommissioning of old nuclear fuel cycle facilities, the personnel involved in the task had to face several problems. In old facilities, the need of large components dismantling and material removal use to present some difficulties, such as lack of available and near electricity supply. Besides this, the spread out of the superficial contamination in the form of dust or aerosols and the exposure of workers should be as much as possible avoided. Then, the selection and availability of suitable tools for the task, mainly those employed for cutting and segmentation of different materials is of significant importance. Slight hand tools, mainly those powered by rechargeable batteries, facilitate the work, especially in areas where the access is difficult. Based on the experience in the dismantling of some old nuclear facilities of IPEN-CNEN/SP, some tools that would have facilitated the operations were identified and their availability could have improved the quality and efficiency of different individual tasks. In this paper different cutting problems and techniques, as well as some available commercial hand tools, are presented as suggestion for future activities.

## 1. INTRODUCTION

Decommissioning is the final phase in the life-cycle of nuclear facilities, after sitting, design, construction, commissioning and operation. The final objective of decommissioning operations is the unconditional release or reuse of sites, facilities, installations or materials for other purposes. It is a process which involves operations such as decontamination, dismantling of plant equipment and facilities, demolition of buildings and structures, and management of the resulting materials. All of these activities take into account the health and safety requirements of the operating personnel and the general public, and also any implications these activities have for the environment. Any decommissioning strategy should include an approach in order to minimize the production of radioactive wastes. The aim of a waste minimization strategy is to maximize the opportunities for release or recycle/reuse of materials, and where residual radioactive wastes are unavoidable, to minimize their volumes for storage and disposal [1].

Nowadays, the decommissioning of nuclear facilities is of great interest because of the large number of facilities which were built many years ago and which will have to be retired from service in the near future [2]. As a result of these decontamination and decommissioning (D&D) operations, a wide range of materials arise. Radioactively contaminated materials arise from the decommissioning of all nuclear facilities such as nuclear power plants, fuel fabrication and reprocessing plants, and research facilities. When decommissioning nuclear facilities, some of the materials arising from the specific activities will be radioactive as a result of activation and/or contamination. In general, a large amount of the materials will be inactive, which means that they will be available for unconditional release.

## 2. DISMANTLING TECHNIQUES FOR DECOMMISSIONING

One important issue related to D&D activities are the cutting techniques used to dismantle all the installation, including metal or concrete structures, and plant and equipment of all kinds.
The dismantling of nuclear reactors and other facilities contaminated with radioactivity generally involves the segmentation of metal items: reactor vessels, tanks, piping and other components. Also, in most facilities to be decommissioned, the cutting and demolition of concrete components is required, often preceded by scarification of the surface in order to remove contaminated areas [3]. Different amounts of wastes, mainly in the form of dust, sludge, metal scrap, concrete, filters and some liquids, etc., may be generated during the application of dismantling techniques. The amount and character of this waste material depends on the type and scale of the dismantling method. The selection of dismantling techniques is mainly defined by the nature of the work to be carried out. However, the generation, collection and adequate treatment of associated waste materials should be carefully considered within the selection process.

The fundamental principles of waste minimization to be followed during D&D have been identified and the essential components are:

- Prevention, i.e. minimization of waste generation;
- Containment, i.e. minimization of the spread of contamination;
- Reutilization, i.e. recycle and reuse of materials and components;
- Consolidation, i.e. reduction of waste volumes.

A large number of factors and constraints are involved in determining an optimized waste minimization strategy during D&D. The key issue is to achieve the right balance between the global economic and environmental impacts of disposal/replacement versus recycle/reuse options. If only local factors and the short time-frame are considered, this may compromise the overall cost effectiveness and safety of a selected option in the longer term, which may extend beyond the local scale.

The cutting of concrete and metallic components can produce debris, dust, smoke and aerosols whose composition and particle size depend on the type of process employed. In addition to the surface contamination released during cutting, beta emitting radionuclides from the interior of activated metals can be released as a result of cutting the material [1]. The workers involved in these operations must be protected against the inhalation of such products. When the parts to be cut are contaminated, the environment must also be protected from the spread of contamination by employment of a suitable containment and ventilation system. Even if the materials are not contaminated, a ventilation system can be useful when cutting indoors.

Typically, mechanical cutting processes, with the exception of abrasive cutting, produce large sized debris and very few aerosols. Filtering or collecting the debris can be done using ordinary HEPA filters and vacuum cleaning. Thermal processes, on the contrary, produce fine debris and large amounts of hot particles, dust and aerosols. The ventilation system must pick these up close to the source. In order to prevent the filters from becoming very quickly saturated, prefiltering devices must be installed. Also, the ventilation system must be designed to allow easy replacement of filters and be shielded against radiation derived from the buildup of active particles in the filters.

A wide variety of processes for the demolition and segmentation of metal and concrete structures has been used and new processes and techniques are continually being developed. These are based typically upon mechanical, thermal, explosive and other principles.

## 3. CUTTING TECHNIQUES

During the decommissioning of nuclear facilities, a wide range of metal structures and components needs to be segmented for easy removal and disposal, as can be observed in the Figure 1. This includes large items such as reactor vessels, pressure tubes, large and small tanks, and all types of piping and ancillary components. Cutting methods used for highly radioactive components, such as pressure vessels or certain reprocessing plant equipment, must provide for remote operation.

**Figure 1. Radioactively contaminated metallic items segmented for storage [4, 5].**

In this section, segmenting processes for all thicknesses of metal components are briefly reviewed in order to assist users in the selection of the most suitable cutting methods.

### 3.1. Thermal Cutting Techniques

#### 3.1.1. Oxygen burning

The oxygen burning technique for the cutting of metals uses a torch assembly carrying a flowing mixture of fuel gas and oxygen which is ignited at the nozzle of the torch. The cutting process depends on the rapid exothermic oxidation of the metal being cut. The fuel gas can be acetylene, propane or hydrogen. The cutting tip of the torch consists of a main oxygen jet orifice surrounded by a ring of preheater jets which exothermically oxidize the fuel gas. When the metal to be cut reaches a temperature of about 800°C [1], the main oxygen jet is turned on and the heated metal is burned away, leaving a reasonably clean cut surface. Since oxidation of the metal being cut is required, only ferrous metals which oxidize readily, such as mild steel, can be cut using this process, as it is can observed in the Figure 2. Stainless steel, aluminum and other non-ferrous metals cannot usually be cut using this process, owing to the formation of refractory oxides with melting points higher than the torch temperature. However, iron or iron–aluminum powder in a flowing mixture can be introduced at the torch nozzle to increase the flame temperature (through the thermite reaction) sufficiently to melt the refractory oxides and permit the cutting of non-ferrous metals.

For mild steel in the 30–100 cm thickness range, cutting speeds are 5–15 cm/min.. Normally, the cutting is done in air. However, some underwater cutting has also been done. The equipment is light enough to allow its easy adaptation for remote operation. Since the process gives rise to dust and aerosols, suitable ventilation, filtering and operator protection are required. Oxygen cutting is widely used in industry, and therefore skilled operatives and good, inexpensive equipment are readily available. The equipment is also easy to set up.

**Figure 2. Segmentation of carbon steel structures using an oxygen-acetylene torch [4, 5].**

### 3.1.2. Plasma arc torch

A plasma arc torch can be used for the rapid cutting of all conductive metals. The process is based on the establishment of a direct current arc between a tungsten electrode and the metal to be cut. The arc is first established between the electrode and the gas nozzle and then carried to the work piece by the flow of gas. The constricting effect of the orifice on both the gas and the arc results in very high current densities and temperatures (10 000–24 000°C) in the stream. The high temperature breaks the gas molecules into high velocity plasma of positively charged ions and free electrons which, in conjunction with the arc, melts the metal being cut and disperses the vapors. Different types of gas can be used depending on the results required. Hydrogen gas gives the highest temperature and a reducing atmosphere. Argon is generally used, but other gases such as nitrogen or air can also be employed. Even higher temperatures can be achieved by directing a radial jet of water onto the plasma stream near the torch nozzle which further constricts the plasma stream and creates higher current densities. These conditions result in reduced smoke, a higher quality cut surface and narrower kerf.

This process produces large quantities of aerosol, smoke and dust with a large number of particles of less than 3 µm in size. If the process is carried out in air, the working place must be well ventilated and exhaust air filtered using prefilters to prevent the rapid 'blinding' of the HEPA filters. During underwater cutting, the water must be filtered for viewing.

## 3.2. Mechanical Cutting Devices

### 3.2.1. Mechanical nibbler

A mechanical nibbler is a punch and die cutting tool which can be used to cut plates and tanks and different kinds can be observed in the Figures 3 and 4. Normally, the punch reciprocates rapidly against the die, 'nibbling' a small amount of the thin sheet metal work piece with each stroke. The nibbler can be operated electrically or pneumatically for dry or underwater applications. The machines are light and can be remotely operated. Typical heavy duty nibblers can cut 5 mm thick stainless steel at a speed of 1 m/min. This process could give rise to small amounts of aerosols coming from loose contamination. The debris can easily be picked up by vacuum cleaning.

**Figure 3. Different kinds of nibblers.**

**Figure 4. Tanks cutting using a nibbler [6-8].**

### 3.2.2. Shears

A shear is a two blade or two cutter tool that operates on the same principle as a conventional pair of scissors. It can be used to cut sheet metal, pipes and small rods and bars. Shears actuated by high hydraulic pressure have been developed which can cut piping of up to 300 mm diameter and 5 mm wall thickness. These tools are light enough to be handled remotely. Shears only give rise to large debris, with no dust or smoke, and only very small quantities of aerosols. An example of hydraulic shear can be observed in the Figure 5.

**Figure 5. Hydraulic shear.**

### 3.2.3. Circular saw machines

Circular cutting machines are used to cut cylindrical components. They are usually self-propelled saws, blades or grinders that cut as they move on a track around the outside of a cylindrical work piece. The machine may be powered pneumatically, hydraulically or electrically and is held to the outside of the pipe, tank or component by a guide chain that is sized to fit the outside diameter. Small machines are relatively inexpensive and easy to use. Contamination control is normally maintained by vacuuming the chips from the cut and by collecting, filtering and recycling lubricants if they are used. Some examples of circular saw machines used for metal segmentation can be observed in the Figure 6.

**Figure 6. Examples of circular saw machines.**

### 3.2.4. Hacksaw and reciprocating saw

Hacksaws, reciprocating and guillotine saws are relatively inexpensive and common industrial tools used to cut all types of metal pieces with hardened steel reciprocating saw blade. Since these saws use mechanical methods to cut the metal, fire hazards are reduced and contamination control is easier. These tools have low operating costs and high cutting speeds and can be used as either portable or stationary units. Some types can also be operated remotely. Portable power hacksaws weighing about 6 kg can be clamped with a chain to a pipe in such a position that the blade contacts the underside of the pipe. This allows the weight of the motor to advance the blade into the work piece about the chain mounted pivot point. The operator can increase the feed pressure manually by applying downward force on the motor body or by suspending weights from the body. In general, blade lubrication is not necessary. Portable hacksaws can cut piping 20 cm in diameter and 0.9 cm thick in about eight minutes [1]. Examples of portable tools, such as hacksaw and reciprocating saw can be observed in the Figure 7.


**Figure 7. Portable tools: hacksaw [6] and reciprocating saw.**

Air or electric motors may be used for both types of portable saw. The set-up time for both types of portable saw is relatively short. Also, once in place, the saws operate without needing any further action to be taken on the part of the operator, thus reducing occupational exposures. Large stationary hacksaws weighing up to 5 Mg can be effectively used in decommissioning since they can cut metal as thick as 60 cm. Cutting rates of about 100 $cm^2$/min make these machines very suitable for segmenting large quantities of material [1]. Locating a facility of this type near decommissioning activities will reduce the costs and exposures associated with handling long sections of pipe. The cost–benefit analysis of such a stationary facility will depend on factors such as the cost of equipment and labor, the amount of material to be cut, the activity levels on the pieces to be cut and the man-sievert worth.

### 3.2.5. Abrasive cutters

An abrasive cutter is an electrically, hydraulically or pneumatically powered wheel formed of resin bonded particles of aluminum oxide or silicon carbide. Such cutters can be used to segment all types of component. Usually, the wheel is reinforced with fiberglass matting for strength. It cuts through the work piece by grinding the metal away, leaving a clear kerf. Since the cutting process generates a continuous stream of sparks, it is unsuitable for use near combustible materials. Tools used for abrasive cutting can be observed in the Figure 8 and a cutting operation is presented in the Figure 9.

Abrasive cutters can be used as portable machines or as part of a stationary workstation. Hand-held abrasive cutters are relatively slow, demand continuous operator attention and are tiring to the operator. Contamination control is a significant problem since the swarf comes off as very small particles. In order to limit the spread of contamination, cutters may be fitted with a swarf containment system and use water lubricants. In most cases, the operator would have to work within a contamination control envelope and wear protective clothing and respiratory protection apparatus. In a stationary set-up, more powerful machines can be used to cut sections of pipe or solid rod into convenient lengths. Units are available that can cut 15 cm diameter solid stock in two minutes and at a much lower cost than with a hacksaw employing a similar cutting speed. Contamination control is much easier with a properly designed stationary unit than with hand-held cutters.

**Figure 8. Rotating abrasive disc: hand held and stationary tools.**

**Figure 9. Cutting operation using an abrasive disc in a stationary machine.**

### 3.3. Alternative Cutting Methods

Other different and specific cutting methods could be mentioned, such as arc saw, thermite reaction lance, circular diamond or carbide saws, laser cutting and explosive cutting.

The arc saw is a circular, toothless metallic blade which can be used to cut any conductive metal without contacting the work piece. The cutting action is obtained by means of a high current electric arc created between the rotating blade and the material being cut. The blade can be made from any electrically conductive material (e.g. tool steel, mild steel or copper) and used with equal success. Blade rotation, which can range from 300 rev./min to 1800 rev./min according to the diameter, assists in the cooling of the blade and the removal of the molten metal from the kerf of the cutting zone. The depth of cut is determined by the diameter of the blade. For example, a 30 cm thick pressure vessel can be cut using a 100 cm diameter blade. The arc saw also permits the cutting of components which are not solid, for example, a heat exchanger where voids alternate with the metal tubes. Cutting rates for the arc saw are much faster than for torch cutting [1].

The thermite reaction lance [1] can cut almost any material encountered in a nuclear facility and is suitable for use on irregular surfaces. This equipment consists of a combination of steel, aluminum and magnesium wires packed inside an iron pipe through which a flow of oxygen gas is maintained. The lance is ignited in air by a high temperature source such as an electric arc or an oxygen burning torch. During operation, the thermite reaction at the tip completely consumes the constituents of the lance and causes the temperature to reach 2200–5000°C, depending on the environment. The thermite reaction lance can be used in air or under water. The operational procedure is the same in both cases, except that the lance must always be ignited in air and the incident angle relative to an underwater work piece must be carefully controlled in order to preserve visibility, since many bubbles are formed during the process. A 3 m lance will burn for about 6 minutes. During cutting, the lance must be hand-held and the operator must be equipped with fireproof protective clothing and a mask. The smoke and dust problems arising from the use of this equipment are similar to those experienced with flame cutting. Since the process generates considerable smoke, a control envelope and ventilation must be provided, particularly if the component is radioactive.

Large diamond or carbide tipped saws [1] are being developed for cutting thick concrete walls and floors. This technique is generally used when disturbance of the surrounding material must be kept to a minimum. These saws can cut through reinforcing rods, although the rods tend to break off diamonds from the blade. The blade is rotated by an air or hydraulic motor. For most applications the saw will be mounted on a guide that also supports its weight. The dust produced by the abrasive cutting is controlled by using a water spray; the spray should be contained in order to prevent the spread of contamination. The abrasive blade produces no vibration, shock, smoke, sparks or slag and is relatively quiet during operation.

Explosive cutting [1] is normally used either when the geometry of an object being cut is too complex to employ other methods or when several cuts must be made simultaneously, e.g. when making two simultaneous cuts in a large concrete beam in the case where it is not practical to provide temporary support to the ends. It is suited to cutting concentric pipes and felling large chimneys. An explosive cutter consists of an explosive core, such as cyclotrimethylenetrinitramine (RDX) or PETN, surrounded by a casing of lead, aluminum, copper or silver. When detonated, the explosive core generates a shock wave that fractures the casing inside the chevron and propels the molten casing into the material to be cut. Cutting is accomplished by a high explosive jet of detonation products and molten casing metal. The small quantity of explosive used usually does not give rise to large volumes of gas or aerosols. However, fragile equipment nearby should be protected from possible projectiles coming from the casing or from the piece being cut.

Laser cutting [1] has been applied to the cutting of both metal and concrete structures. A high power gas laser generates infrared radiation which can be focused using water cooled reflective optics to produce a beam with power densities capable of cutting steel or concrete. However, the cutting can only be carried out in air, since water would diffuse the laser beam excessively. The laser gas can be inert ($CO_2$, He, $N_2$) or reactive ($O_2$, air). A $CO_2$ laser uses an inert gas as the lasing medium, with a typical gas composition of about 78% He, 18% $N_2$ and 4% $CO_2$. The laser beam melts and vaporizes the material being cut and removes it from the cutting area by means of a high velocity gas jet. Lasers with power ratings in the range of 1–15 kW can be used to cut concrete or steel. A $CO_2$ laser cutting system consists of a laser beam generator and associated controls, high voltage electricity and gas supplies, beam handling and focusing optics, a cooling system and a nozzle assembly. High power laser cutting systems tend to be relatively expensive and require large spaces in which to operate. Although progress has been made in using laser technology to assist decommissioning, it would appear that much more work is required before it becomes a viable option for cutting or drilling massive concrete.

## 4. CONCLUSIONS

The dismantling and decommissioning task can be carried out by means of tools and equipment normally used in the industry. The choice of the better equipment must be examined case by case. Different methods and tools, most of them relatively inexpensive, are available. In the dismantling of old nuclear facilities, it is very common to have difficulties in the supply of electric power and/or to develop the work in remote places with complicated access. In these cases, smaller tools, powered by batteries may be the better choice. The main objective of this paper was to present some alternatives in terms of tools useful for the decommissioning task, some of them based in the experience gained with some actual decommissioning projects, including the IPEN's experience.


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