



## **Radiation Effects: Recommendations for Safe Plasma/Flame Cutting Operation**

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### **Authors' contributions**

*This work was carried out in collaboration between all authors. Author SBM designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author AAA managed the literature searches and monitored flame/plasma cutting operations. Author KJA collated and analysed reported effects from flame/plasma operations. Author OSA designed and managed the workshop process. Author ARA interpreted findings to draw the conclusions. All authors read and approved the final manuscript.*

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**Case Study**

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### **ABSTRACT**

Plasma cutting has been a revolutionary method of processing metals as it provides precision cutting with a smooth finish. The Plasma Arc Cutting machine is an important machine used for producing fine cuts and creating shapes in materials. In addition to high energy radiation (ultraviolet and visible) which plasma arc cutting generates, the intense heat of the arc also generates substantial quantities of fumes and smoke from vaporizing metal in the kerf. With a reflection on a case study, this paper examines the working processes of the machine and the effect on the health of operators or any unsuspecting member of the public. With the safety regulations and recommendations from certified bodies, recommendations are made to ensure safety and limitations of health hazards during the use of the machine.

**Keywords:** *Plasma arc cutting; health and safety; flame cutting; non-ionising radiation; fumes; Nigerian establishment.*

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## 1. INTRODUCTION

Plasma (arc) cutting was developed in the 1950s for fine precision cutting of metals that could not be flame cut, such as stainless steel, aluminium and copper. The plasma arc cutting process uses electrically conductive gas to transfer energy from an electrical power source through a plasma cutting torch to the material being cut. The plasma gases include argon, hydrogen, nitrogen and mixtures, air and oxygen. Normally, a plasma arc cutting system has a power supply, an arc starter circuit, and a torch. The power source and arc starter circuit are connected to the cutting torch through leads and cables that supply proper gas flow, electrical current flow, and high frequency to the torch to start and maintain the process. The arc and the plasma stream are focused by a very narrow nozzle orifice. The temperature of the plasma arc melts the metal and pierces through the workpiece while the high velocity gas flow removes the molten material from the bottom of the cut, or the kerf. Owing to its extremely high cutting speeds (especially with thin materials) and narrow heat-affected zone, the technique is also used today for cutting non-alloy and low-alloy steels.

In addition to high energy radiation (Ultraviolet and visible) generated by plasma arc cutting, the intense heat of the arc creates substantial quantities of fumes and smoke from vaporizing metal in the kerf [1]. Dependent upon the power utilised, plasma torches can cut material in the order of 150 mm thick. Such thickness usually means slow cutting rates and is normally only used for stainless steel or non ferrous materials. Plasma cutting of mild steel is typically employed on thinner material (less than 20 mm) when very high cutting speeds – in the order of meters per minute – can be employed [2].

According to Kris Bancroft, Plasma Arc Cutting (PAC) is an efficient method for making high-quality cuts from stock. The process works by conveying an electric arc through some form of gas mixture (oxygen, nitrogen, argon, compressed air, etc.) through a constricted opening. This process causes the gas temperature to increase to the point where it enters the fourth state of matter – Plasma (Kris Bancroft, 2003). Plasma arc cutting can be characterized in terms of two distinct speeds. At cutting speeds above, the plasma jet does not cut through metal plate. At speeds below, the molten metal from the kerf sticks to the bottom

of the plate, forming the so-called dross. Plasma can cut in a wide range of cutting parameters (currents, metal thicknesses and nozzle orifice diameters) for plasma arc cutting of stainless steel materials. The plasma arc cutting process employs a plasma torch with a very narrow bore to produce a transferred arc to the work piece at an average current density of within the bore of the torch. The energy and momentum of the high-velocity plasma jet generated by the plasma torch melts, vaporizes and removes the metal from the region of impingement of the nozzle [3].

Welding, cutting and brazing are hazardous activities that pose a unique combination of both safety and health risks to more than 500,000 workers in a wide variety of industries. The risk from fatal injuries alone is more than four deaths per thousand workers over a working life time [4].

## 2. POTENTIAL HAZARDS

Welding and cutting arcs produce electromagnetic radiation. The type of radiation produced by electric arc and fuel gas processes is known as non-ionizing radiation, which is also the type of radiation produced from most naturally occurring radioactive materials. However, unlike natural radioactivity which is common in the rocks and soils that make up our planet just like it is in the water and the oceans and virtually every material on earth [5]; electric arc and laser welding emit ultraviolet (UV), visible light and infrared (IR), gas welding and gas cutting emit visible light and IR radiation.

BOC Canada in 2006 defined a hazard as something that has the potential to cause harm and defined risk as the likelihood that the hazard will actually cause harm under the prevailing conditions [6]. Occupational Exposure Limits (OELs) are the maximum permissible concentrations of a hazardous substance that most healthy adults may be repeatedly exposed to without suffering adverse health effects [7]. Just like the potential effect of radiation on the body depends on the type and intensity of radiation, the distance you are from it and the duration of exposure; the fume generation rates from thermal metal cutting also vary with the process parameters such as cut rates, total cutting time and material thickness. Additionally the cutting consumables, surface coatings, base metals or any other contaminants present within the atmosphere will also be part of the fume

make-up. However, without proper filtration and / or other dust collection measures the fume and smoke generation can be significant. The plasma arc process produces very bright ultraviolet and infrared rays. These will damage the eyes and burn the skin if not properly protected [8].

Non-ionizing radiation from welding and cutting can cause damage to skin and eyes, UV radiation can cause burns to unprotected skin and eyes (arc-eye), exposure to X-rays can cause serious damage to body tissues, including skin damage, cancer, leukaemia and reduced fertility; it can also lead to premature death. The effects of IR and UV radiation are not normally felt until some time after exposure [6].

Carcinogenicity depends upon many factors, including the properties of the materials of exposure, the adequacy of protective equipment used, the individual's susceptibility, and other factors. Certain metals, such as chromium VI compounds and nickel, have been reported to cause cancer. The possible confounding roles of cigarette smoking, environmental agents, and other non-work related factors must be considered [9].

Exposure to fumes over time and in sufficient concentrations have been linked to numerous respiratory and health related illnesses. Thermal cutting processes on base metals such as stainless steel, low alloy steels, hard facing materials and other alloys may release materials that contain manganese, chromium, cadmium, lead, nickel or other known hazardous substances which have tightly controlled PEL (Permissible Exposure Limits) established by local and national government agencies. In addition to health risks, uncontrolled thermal cutting fumes result in reduced worker productivity, product quality problems, factory maintenance issues and environmental concerns [10].

Arc eye or welder's flash is caused by the action of ultraviolet (UV) light on the outer surface of the eyeball. The symptoms develop some time, generally an hour or more after exposure. The eyes are painful, often with a gritty feeling, red, watering and sensitive to light. The eyes should be bathed with cold water and a light covering applied. If there is any doubt about the severity of the injury or a risk that a foreign body may

have entered the eye, seek medical aid urgently.

Exposure to excessive amounts of zinc, copper, magnesium and some other metal fumes can cause metal fume fever, with symptoms similar to influenza. Some hours after inhaling the fume the individual complains of tiredness, headache, aching muscles, thirst, a sore throat, a cough, and sometimes of a tight feeling in the chest [11]. The individual will develop a high temperature, have shivering attacks and perspire profusely. Complete recovery normally occurs in 24 to 48 hours. If a worker suffers in this way, and influenza is ruled out, fume levels should be investigated; if no specific pollutant is identified, seek medical advice.

The inhalation of cadmium fumes gives rise to similar symptoms, in some cases followed by acute inflammation of the lungs, which can be fatal. Immediate medical advice should be sought if there is a possibility of illness being due to cadmium fume [11].

### 3. OUR CASE STUDY

A case study of Plasma CNC Gantry Cutting Machine (CNC-3000) in our workshop is considered in this study. Operational reports from operators of the machine provided the basis for technical assessment and recommendations. Our case study (Fig. 1), which is a Plasma CNC Gantry Cutting Machine (CNC-3000) with maximum cutting length of 4000 mm, maximum cutting width of 2200 mm, maximum cutting speed of 100-150 mm/min, flame cutting thickness of 5-70 mm and plasma cutting thickness of 2-25 mm. The machine is owned by a government engineering and research institute in Nigeria.

#### 3.1 Reported Effects felt from operation of Plasma CNC Gantry Cutting Machine (CNC-3000)

Although these reported effects are in consonance with some of the documented effects from operation of a plasma cutting machine, they have not been verified with medical procedures such as checking the eyesight and skin of the operators, determining the blood parameters of the operators, and putting other external factors which could cause some of those effects into consideration before and after every operation of the machine. This

is due partly to the limited facility to carry out such procedures and partly to the documentation processes required before and after every usage of the machine. The effects are: Eyesight defects (watery eyes and aches in the eyes after continuous operation with no eye goggles), headache, dizziness and general weakness.

It is worthy of mention however, that the effects listed above were reported from operators of the machine after a continuous operation lasting several hours.

#### 4. RECOMMENDATIONS

High frequency (H.F.) can interfere with radio navigation, safety services, computers, and communications equipment. Only qualified persons familiar with electronic equipment must perform the installation. The cutting operations area must be located in a way that other workers are not exposed to either direct or reflected radiation. It is essential for effective risk management that personnel at all levels are adequately trained. Indeed, in many acts and statutory instruments, it is mandatory that training be given to ensure that welders and others operate equipment and use processes safely. They are also required to recognize and have an understanding of potential hazards and the safety procedures designed to eliminate or reduce risk [6]. Personnel must be made aware of the risks and potential hazards involved with the operation of the machine, as confirmed by the American National Standards Institute fundamental recommendation that personnel shall be informed of the potential hazards from fumes, gases, electric shock, heat, radiation, and noise [12].

Electromagnetic energy given off by an arc or flame can injure workers' eyes and is commonly referred to as radiant energy or light radiation. For protection from radiant energy, workers must use personal protective equipment, such as safety glasses, goggles, welding helmets, or welding face shields to protect the eyes from sparks and the rays of the arc when performing or observing plasma arc cutting or gouging. This equipment must have filter lenses with a shade number that provides the appropriate level of protection. A shade number indicates the intensity of light radiation that is allowed to pass through a filter lens to one's eyes. Therefore,

the higher the shade number, the darker the filter and the less light radiation that will pass through the lens.

Glasses, head-shield, and filter lens should conform to the ANSI Z87.1 standards. The plasma arc process produces very bright ultraviolet and infrared rays. These will damage the eyes and burn the skin if not properly protected [8].

Tables 1 and 2 show the OSHA and the ANSI recommendations for the type of protective goggles to wear during different cutting procedures.

It is important to keep the head out of the fumes, operators must not inhale the fumes. To protect against the fumes that cover the air as the operator leans over the workpiece – especially fumes of stainless steel which boasts the presence of Chromium, powerful fume extractors and face masks are recommended. Exposed skin should be protected with adequate gloves and clothing according to ANSI Z49.1.

It is also instructive to recommend that factories and organisations purchase CNC plasma cutting machines which have a built in fume extraction system to limit the fumes escaping into the air.

Moreover, it is a beneficial practice on laser cutting, plasma cutting and oxy cutting applications to clean overly oily parts and use spark traps or some other form of pre-separator to minimize the risk of any fugitive sparks to the dust collector. If the conditioned air is to be returned into the workspace, safety filters might need to be considered based on the base metals and other contaminants collected [13].

Suggested personal protective equipment include: Respirators, ear muffs, protective clothing, gloves, boots, helmets, eye protection and face shields. Use of suitable clothing including gloves made from durable flame-resistant material to protect the operator's skin and that of other workers from the arc rays. Furthermore, it is important to protect other nearby personnel with suitable non-flammable screening and/or warn them not to watch the arc nor expose themselves to the arc rays or to hot spatter or metal [14].

**Table 1. Filter lenses for protection during plasma Arc cutting operations**

Operation	Arc current (Amperes)	OSHA minimum protective shade number	ANSI & AWS shade number <sup>1</sup> Recommendations	Reference
Light	Under 300	8	9	[15]
	300 to 400	9	12	[15]

**Table 2. Recommended shade numbers for various Arc current**

Arc Current (Amperes)	Minimum protective shade no.	Suggested shade no.	Reference
Less than 20	4	4	[12]
20 – 40	5	5	[12]
40 – 60	6	6	[12]
60 – 80	8	8	[12]
80 – 300	8	9	[12]
300 – 400	9	12	[12]
400 – 800	10	14	[12]



**Fig. 1. Image of the Plasma CNC Gantry Cutting Machine (CNC-3000)**

<sup>1</sup>As a rule of thumb, start with a shade that is too dark to see the weld zone. Then, go to a lighter shade which gives a sufficient view of the weld zone without going below the minimum. During oxygen gas welding or cutting where the torch produces a high yellow light, it is desirable to use a filter lens that absorbs the yellow or sodium line in the visible light (spectrum) of the operation.

## 5. CONCLUSION

The Plasma CNC Gantry Cutting Machine (CNC-3000) is a very important and efficient tool in cutting materials of about 150 mm thick using extremely high cutting speeds with the production of high energy radiation and intense heat. Plasma can cut in a wide range of cutting parameters (currents, metal thicknesses and nozzle orifice diameters). However, some factors are to be given careful thought in order to harness fully all the high points of the Plasma cutting machine while keeping the operators and environment safe; some of which are the generation of non- ionising radiation and the exposure to fumes which could contain zinc, copper, magnesium and cadmium. With the recommendations garnered by this report, it is believed that industries and owners of Plasma cutting machines or similar equipments generating non-ionising radiation (especially ultraviolet light) and metallic fumes will be able to maximise the input of their operators because by ensuring a safer working environment will in turn yield quality production from the machine.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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