# Waste management in a Uranium Enrichment

# Plant

F.S. PEREIRA

Amazul

São Paulo, Brazil

Email: flavio.pereira@amazul.gov.br

**Abstract**

With the population growth and the technological advances, the demand for efficient and environmentally friendly electric power sources is a certainty that all countries will face in a near future. Despite the usual concepts of green energy, one must agree that nuclear energy is one of the few technologies currently available with low carbon emissions, highly efficient and it is a promising alternative to be used for carbon capture to reduce global climate change effects. The raw material necessary in nuclear power plants is the nuclear fuel obtained through the enrichment of the uranium isotope, 235U, present in the uranium ore. All commercial technologies of uranium enrichment are based on processing uranium hexafluoride (UF6) which is a toxic molecule and must be handled properly. Thus, any plant that process UF6 must neutralize the molecule in any event that can expose the substance to the atmosphere which will result as process waste. The main goal of this article is to present a literature review of waste management of UF6 used in enrichment plants to produce low enriched uranium, up to 5% of 235U. In this article it is shown the radiological and toxicological aspects of the UF6, the means to neutralize the molecule and handle gaseous, liquid and solid waste of a Uranium Enrichment Plant.

## INTRODUCTION

The demand for energy increases with human development both in terms of population and technology. Countries' energy demand can be divided into three areas [1]: electricity generation, heating and transport. Currently, all these areas rely almost exclusively on fossil fuels as their main source of energy. Dependence on a scarce, non-renewable energy source is an international concern due to fossil fuel prices and its association with climate effects [2]. Regarding the harmful climatic effects, it can be mentioned: air pollution [3] and the emission of greenhouse gases (GHG) such as CO2, CH4, N2O and CF4 [4]. Many countries are working to stabilize and reduce GHG emissions in the long term [3] by replacing the primary energy source and restricting the use of fossil fuels for residential activities and material for chemical industries [1]. This substitution is not an easy task, as it must consider several aspects such as cost, scarcity of resources, environmental impact, and public acceptance. The main current sources of alternative energy to fossil fuels are wind, water, solar and nuclear. These alternative sources also generate GHG emissions, but in much lower amounts compared to the emissions from fossil fuels-based sources. It should be noted that for each type of energy source there is a release of different GHG at different stages of the energy chain, especially during the manufacture of structural materials. Thus, the correct comparison between the environmental impacts caused by each energy source is a complex task that requires several conversion factors [3]. Table 1 provides a comparative data between different energy sources and GHG emission calculated in CO2 equivalent per kWh(e).

TABLE 1. GHG EMISSIONS COMPARISON AMONG DIFFERENT
TYPES OF ENERGY SOURCES [5]

|  |  |  |  |
| --- | --- | --- | --- |
| Energy Source |  |  | Average GHG emission(CO2/kWh(e)) |
| Water |  |  | 15 – 25 g |
| Fossil Fuel |  |  | 600 – 1200 g |
| Nuclear |  |  | 10 – 130 g |
| Solar |  |  | 90 – 150 g |
| Wind |  |  | 15 – 25 g |

Despite the environmental appeal of wind and solar energy sources, these sources are intermittent, dependent on the availability of wind and solar radiation, to generate electricity. Such sources are considered fuel-saving technologies, as their infrastructure depends on another energy source and methods for its storage, i.e., in the form of heat by heating water or molten salts, pumping water to store potential energy, compressed air or in chemical batteries and hydrogen cells [1]. In addition, wind and solar energy sources are based on technologies that depend on very scarce chemical elements, which cannot be applied in a global scale, such as neodymium, used in electric motors and generators, lithium, used in batteries, and platinum, used in hydrogen cells [6].

Climate change also negatively affects the use of water-based energy sources, as in the case of hydroelectric plants, due to the increase in the frequency and extension of drought periods.

The heat and electricity generation of a nuclear power plant produces low GHG emissions [5], however, the upstream processes generate considerable GHG emissions [3], especially during refining and conversion of uranium ore into uranium hexafluoride [4]. The lower the uranium ore grade, as uranium concentration per ton processed, the greater the amount of GHG emitted along the nuclear fuel chain [4]. The two main arguments against the use of nuclear energy are not associated with GHG emissions, but with public fear of a nuclear accident and the possibility of increased production of nuclear weapons [5]. Both arguments are not supported by the data collected during the approximately 70 years of use of this energy source. Another disadvantageous aspect of nuclear energy is the average time for the operation of a new plant, around 15 years [6]. For comparative purposes, a wind or solar plant starts operating, on average, in 3 years [6]. Even so, nuclear energy through the fission of atomic nuclei appears as one of the few energy sources already consolidated and capable of delivering, in a safe, sustainable, economical and reliable way, the enormous amounts of energy necessary for the operation of modern industrial societies [1].

Each stage of the nuclear energy source chain has different types of waste treatments. A stage little explored in the literature is the uranium enrichment for energy generation purposes, up to 5% of 235U. Thus, the objective of this text is to present the processes related to the management and waste treatment used in a uranium enrichment plant.

## Uranium enrichment

The uranium enrichment stage, within the entire nuclear energy source chain, is the stage with the lowest environmental impact. Mining and converting the ore into UF6 generate significant amounts of harmful metallic elements such as Arsenic (As), Chromium (Cr), Lead (Pb), Copper (Cu), Molybdenum (Mo), Nickel (Ni), Mercury (Hg), Vanadium (V) and Selenium (Se) [7]. The mining activity also presents difficulties in uranium inventory control, as uranium particles are dispersed in the environment in the form of dust during processing and transport. However, in the enrichment stage there are no chemical reactions directly involved in the process, only UF6 in gaseous form is used as an input for the two most used commercial methods in the industry [5]: enrichment by gaseous diffusion, or enrichment by centrifugation. Enrichment by gaseous diffusion is based on the difference in diffusion velocity between isotopes, the heavier the isotope, the lower its diffusion velocity. Enrichment by centrifugation is based on the radial gradient of isotope concentration due to the centrifugal force generated by the high rotation of the centrifuges, the heavier isotopes being concentrated in the outer part and the lighter isotopes being concentrated in the inner part of the centrifuges. Fig. 1 shows a diagram of the uranium enrichment process, where the feed is kept hot to keep the UF6 in a gaseous state and the product and tailings are cooled to accelerate the UF6 desublimation and storage.

**48Y**

**48Y**

**30B**

Enrichment process

Hot

Cold

**Feed**

UF6 natural

concentration

~0.7% of 235U

**Tail**

UF6 less than

0.7% of 235U

**Product**

UF6 more than

3.0% of 235U

*FIG. 1. Diagram of Uranium Enrichment process*

Fig. 1 shows that under ideal operating conditions there would be no need for waste treatment systems, as all the processed natural uranium would later be stored as a product (enriched uranium) or tails (depleted uranium). This does not actually occur because the entire system operates at sub-atmospheric pressures, and the contamination of the system by gases present in the atmosphere such as oxygen, nitrogen, argon, and water vapor is inevitable. This contamination has two immediate effects on the process: the first is the increase in pressure in the system that needs to be constantly depressurized via vacuum pumps; the second is the chemical reaction between UF6 and water, as followed:

$$UF\_{6}+2H\_{2}O⇌UO\_{2}F\_{2}+4HF$$

Therefore, the lower the leakage of the process components, the smaller the loss in the form of waste.

## Waste treatment in a uranium enrichment plant

The aim of a system for the management and treatment of radioactive waste at any stage in the nuclear energy chain is to ensure the protection of human health and the environment without causing a burden for future generations [8]. When dealing with radioactive waste, each country has specific laws, regulations, and responsibilities, but safe radioactive waste management must be a systematic activity, regardless of location. All radioactive waste must be characterized so that its physical, chemical, and radiological properties are determined, in all stages of the waste treatment. This step is essential so that each type of waste is treated and disposed correctly, meeting its storage and disposal requirements. Transport between treatment steps must also be considered. The storage method must be designed in such a way that the waste is isolated, safe and controlled [8]. A uranium enrichment plant has gaseous, liquid, or solid wastes and those presents chemical and biological hazards, in addition to the radiological risks associated with them.

### Gaseous waste

The HF generated by the reaction between UF6 and water and the UF6 itself are the main gaseous wastes in a uranium enrichment plant. From the moment that a natural uranium feed cylinder is connected to the process, these gases are present. The amount of these gases outside the enrichment process is small, originating from two activities: the connection of new feed cylinders and the purging of the process lines by vacuum systems.

The UF6 present in the feed cylinders is stored in its solid form at room temperature (approximately 25°C) and at a pressure below atmospheric, thus is expected contamination with atmospheric gases inside these cylinders. Whenever a new feed cylinder is connected to the enrichment process, the gases present in the cylinder are purged in order to remove these contaminants, mainly HF. These gases are routed to process exhaust systems that are connected to scrubbers filled with basic solutions such as potassium hydroxide (KOH). The main neutralization reactions are:

$$2UF\_{6}+14KOH⇌K\_{2}U\_{2}O\_{7}+12KF+7H\_{2}O$$

$$HF+KOH⇌KF+H\_{2}O$$

Potassium diuranate (K2U2O7) is a water-insoluble compound, while potassium fluoride (KF) is soluble. These two compounds are intermediate products within the waste treatment sequence.

### Liquid waste

Liquid waste is generated in the most diverse activities such as washing rooms, sewage from showers and sinks in restricted areas, materials decontamination, condensed water from heat exchangers, gas scrubbers’ solutions and fluor-based oils used in rotating equipment that has contact with the UF6. The main properties from effluents in an enrichment plant are the concentration of fluoride ions, the concentration of uranium and the pH of the effluent.

In the washing and decontamination of materials and parts, acidic solutions are used so that the uranium compounds are dissolved [9]. These wastewaters are neutralized with basic KOH- solutions. This way, most of the uranium is precipitated in the form K2U2O7. All precipitated uranium is retained in filters and stored in drums as solid waste. The liquid fraction that is not retained by the filtration process is treated to precipitate the dissolved KF, as seen in the follow reaction:

$$2KF+Ca\left(OH\right)\_{2}⇌2KOH+CaF\_{2}$$

Calcium fluoride (CaF2) is insoluble and can be removed via filtration, while KOH can be reused in the neutralization processes.

These reactions allow the concentration of fluoride and uranium ions within the existing limits for disposal, in accordance with current legislation. If necessary, reverse osmosis systems can be used to further reduce fluoride and uranium ions [10].

Oil wastes are treated in water/oil separator systems, with the oil part stored inside drums.

### Solid waste

Solid waste in a uranium enrichment plant can be divided into two categories: depleted uranium resulting from the enrichment process itself, and uranium from gaseous and liquid waste treatment processes. The largest amount of solid waste is depleted uranium. This waste can be stored for a long time inside the 48Y cylinders, as it will be in solid state and at lower pressure than atmospheric. As an alternative, there is the reduction into metallic uranium to be used as radiation shielding or the production of oxide-mixed nuclear fuels [5]. From a radiological point of view, the solid waste containing uranium will have concentrations of 235U equal to or lower than the natural one, presenting no radiological or criticality risk.

## Conclusions

The nuclear energy has a low environment impact compared with other sources. To achieve the production of electricity via nuclear power it is necessary several stages from mining, conversion in uranium hexafluoride, enrichment, and conversion in nuclear fuel. The uranium enrichment is the least stage mentioned in the literature. Although its complexity to be achieved, the enrichment process is based on simple physical reactions. This feature allows a safe and low waste process. All waste produced in an enrichment plant can be easily treated with aqueous solutions or stored inside reliable vessels.

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References

[1] BROOK, B.W. et al., Why nuclear energy is sustainable and has to be part of the energy mix, Sustain. Mater. Technol. **1**–**2** (2014) 8.

[2] AL-MULALI, U., Investigating the impact of nuclear energy consumption on GDP growth and CO 2 emission: A panel data analysis, Prog. Nucl. Energy **73** (2014) 172.

[3] VAN DE VATE, J.F., Comparison of energy sources in terms of their full energy chain emission factors of greenhouse gases, Energy Policy **25** 1 (1997) 1.

[4] NORGATE, T., HAQUE, N., KOLTUN, P., The impact of uranium ore grade on the greenhouse gas footprint of nuclear power, J. Clean. Prod. **84** 1 (2014) 360.

[5] LENZEN, M., Life cycle energy and greenhouse gas emissions of nuclear energy: A review, Energy Convers. Manag. **49** 8 (2008) 2178.

[6] JACOBSON, M.Z., DELUCCHI, M.A., Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials, Energy Policy **39** 3 (2011) 1154.

[7] LAIRD, K.R., DAS, B., CUMMING, B.F., Enrichment of uranium, arsenic, molybdenum, and selenium in sediment cores from boreal lakes adjacent to northern Saskatchewan uranium mines, Lake Reserv. Manag. **30** 4 (2014) 344.

[8] AGENCY, I.A.E., INTRODUCTION of nuclear waste iaea, 111 (1995).

[9] GERENUTTI, M. et al., Assessment of liquid disposal originated by uranium enrichment at Aramar Experimental Center São Paulo—Brazil, Environ. Monit. Assess. **184** 7 (2012) 4425.

[10] LIN, K.-L., CHU, M.-L., SHIEH, M.-C., Treatment of uranium containing effluents with reverse osmosis process, Desalination **61** 2 (1987) 125.