CHAPTER 25

A REVIEW OF NUCLEAR AND RADIOACTIVE WASTE MANAGEMENT WITH REFERENCE TO AFRICA

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Introduction

This chapter highlights and defines the types of nuclear and radioactive waste generated based on internationally accepted standards and terminology. It discusses the few African countries, which produce nuclear and radioactive waste, and those that have the potential to produce nuclear and radioactive waste. Some of the most likely factors such as technical, economic, institutional, aesthetic and ethical affecting the handling, treatment, storing and disposal of these categories of waste are considered. A justification is argued for very minimal nuclear and radioactive waste production in the less developed countries compared to that of the more developed countries. *Laws and legislation on nuclear and radioactive waste management are either lacking or not stringently applied in African countries.* Mutinational corporations (MNCs) from the developed countries tend to exploit the economic situation of less developed countries in attempting to involve agencies, institutions and private companies in illegal trade of nuclear and radioactive waste. With increasing global demand for the use of nuclear energy (research, civil and military reactors), it is debatable if Africa will continue to remain a continent with the lowest level of nuclear and radioactive waste generation.

Overview

The Allied Powers forced the Second World War to an end when two atomic bombs were dropped in Hiroshima and Nagasaki, both cities in Japan. Uranium-238 was converted to Plutonium-239 with the release of energy having the capabilities of destroying living cells. The tremendous catastrophic aftermath resulting from the radioactive ionisation release opened the eyes of Western Powers to a new era and application of nuclear energy. With the introduction of nuclear technology, humankind's living standard has been ameliorated in the areas of energy supply, medicine, economic development and environmental protection. New applications of nuclear technology are researched on and introduced at an accelerated rate.

With increasing global demand for this form of energy and the discouragement in the usage of fossil fuel, a tendency is ensured towards the generation of more nuclear and radioactive waste. It becomes inevitable for man to clean his

habitat for both himself and posterity. The politics, methods and techniques, laws and legislation and safety of cleaning humankind's environment due to the generation of nuclear and radioactive material is nuclear and radioactive waste management.

This form of waste management deals with the treating, storing and disposing of nuclear-related spent fuel and waste generated during the application of nuclear and radioactive material for individual and national benefits. Radioactive waste is any material having a concentration of radionuclides greater than those deemed safe by national and international authorities, with an unforeseen use (World Datom, 1998).

This chapter reviews from existing literature and available data through the Internet, the generation and classification of nuclear and radioactive waste. It discusses how nuclear and radioactive waste is currently managed. It focuses on the prevalent African situation and attempts to forecast a future trend world-wide in the application of nuclear and radioactive energy and their disposal.

Generation of Nuclear and Radioactive Waste

Basic Nuclear Chemistry

In any radioactive reaction or nuclear reaction, at least one of three types of emissions occurs during the reaction. These are:

- *Alpha-Radiation* which gives rise to **alpha particles,** which are Helium-4 nuclei;
- *Beta-Radiation* which gives rise to **beta particles,** which are fast electrons emitted from nuclei; and
- *Gamma-Radiation* which gives rise to **gamma photons,** which are very high frequency short wavelength electromagnetic radiation.

In these reactions, either a nucleus splits into two or more daughter nuclei (radioactive decay), a nucleus is caused to disintegrate (nuclear fission) or two or more nuclei are caused to combine to form one nucleus (nuclear fusion). In all the three types of nuclear reaction, nuclear energy and nuclear waste are released. The number of radioactive nuclei in a radioactive decay series decreases exponentially with the law of radioactive decay.

Generation of Waste

Nuclear and radioactive waste can be generated in six different ways. These are as follows:

- ❑ Naturally occurring;
- ❑ Tailings dump;
- ❑ Mining activities;
- ❑ Research for new applications and increase in knowledge;
- ❑ Civil applications; and
- ❑ Military applications

Naturally occurring isotopes of radioactive elements, such as Uranium, exist in nature although their isotopic percentage compositions are usually less than 5%. This explains why radioactive isotopes need to be enriched in order to have a high concentration required for their various applications. Uranium-235, most needed isotope in nuclear technology, occurs naturally as 0.7% of the three isotopes of Uranium, and must be enriched to 3% before it can be of any nuclear application.

Tailings dumps from the exploitation of certain types of mines may be constituted of certain percentages of nuclear and radioactive substances such as oxides of uranium. In some deposits of precious and semi precious minerals, radioactive substances may occur at levels profitable for exploitation as by-products. In the extraction of gold, for example the East Rand Gold and Uranium Company in South Africa, uranium is a by-product. The most commonly mined uranium mineral is pitchblende (Uranium oxide).

Universities and research institutions generate nuclear and radioactive waste substances. In a variety of civil applications of nuclear technology (medicine, energy, agriculture, water quality etc.), and in the manufacturing of nuclear weapons, and in the researching with radionucleids high level and low level waste are generated. *Main sources of radioactive wastewater emanate from nuclear reactors, isotope laboratories, nuclear research centres, and from the processing of uranium ore, laundering of protective clothing used by workers of radioactive materials, and from laboratories in which radioactive substances are applied for therapeutically* (Jorgensen, 1979). Ionisation radiation equally releases waste in what is now known as electronic smog: cannot be seen or even felt! Recent revealed statistics show that nuclear power generation facilities in the world produce about 200 000 metres cubed of low and intermediate level (LILW) and 10 000 metres cubed of high level waste (HLW) annually (World Datom, 1998).

Classification of Nuclear and Radioactive Waste

All nuclear waste contains at least a quantity of long-lived radionuclides. The wastes are categorised based on their origin. It should be noted that all transuranic elements are artificial, unstable and radioactive in nature, emitting alpha-particles with very long half-life. To this effect, five categories of radioactive waste are identified (Institute for Energy and Environmental Research, 1998). These classes are:

- **High Level Waste (HLW):** This class includes irradiated commercial reactor fuel (spent fuel), and reprocessing liquid waste;

- **Transuranic Waste (TRU):** This class of waste contain elements with protons greater than 92. The half-life should be greater than 20 years and concentrations greater than 100 nanocuries. These radioactive (unstable) elements are neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium and nobelium;

- **Naturally Occurring and Accelerator Produced Radioactive Materials:** These are orphan waste such as Radium-226 and Thorium-230 produced outside the nuclear fuel cycle.

- **Low Level Waste (LLW):** This category of waste includes all other representations of nuclear and radioactive waste not mentioned in the three categories above. This class is broad and includes short-lived and long-lived radionuclides;

- **Mixed Waste:** This contains both radioactive and hazardous materials.

An analytical study (Canadian Coalition for Nuclear Responsibility (1996) of one of the sources of nuclear and radioactive waste, found a total of not less than seventy-nine poisonous isotopes from forty-five chemically identified elements to occur in spent nuclear fuel. The list includes six isotopes of Uranium, five isotopes of Plutonium, seven isotopes of Thorium, Tritium, Lead-205 and Lead -206.

Nuclear and Radioactive Waste Production in Africa

Africa is not as involved in nuclear technology as Europe, Asia or North America. However, there are a number of mining activities and nuclear energy utilisations, particularly in South Africa, which demand the management of waste. Two most used radioactive elements that generate waste are Uranium and Plutonium. Uranium is the principal fuel for nuclear reactors and main raw material for nuclear weapons. In 1996, close to 35 200 tons of Uranium were

produced in 38 countries around the world, of which about 22% was from Africa (Uranium Institute, 1998), (see Table 25.1). Canada alone produced 11 788 tons. South Africa has Africa's largest reserve. amounting to 317 000 tons, followed by Niger and Gabon.

Table 25.1: Uranium Production in Africa.

Country	Tonnage	%age
Gabon	565	1.6
Namibia	2452	7.0
Niger	3320	9.4
South Africa	1440	4.11

Apart from the four countries mentioned in Table 25.1 above, sixteen other African countries including Nigeria and Cameroon are known to have significant Uranium deposits.

Uranium mining and its isotopic enrichment are complex industrial processes requiring the use of nitric acid, hydrofluoric acid and magnesium. Plutonium (Pu) is the second transuranic element and is not known to exist naturally although a case has been reported in Gabon. It must be produced artificially from Uranium. One kilogram of Plutonium-239 produces heat energy equivalent to 22 million-kilowatt hour of heat. To detonate a kilogram of it, an explosion is produced with the equivalent of 20 000 tons of chemical explosives. Plutonium has been used in space missions (Apollo series) to empower seismic and other equipment on the lunar surface.

Waste Management Techniques

Handling

Owing to the instability of radionuclides, and the health and socio-economic implications of their waste occurrences, nuclear waste management involves highly specialised technical skills, appropriate disposal facilities and good economic planning. The radioactive nature, health hazards and the amount of energy release associated with both natural and induced decay of these substances demand that they be handled with very great caution.

Treatment

The main concern in treating radioactive waste is to reduce its volume and render it inactive or immobile. Treatment options in volume reduction include

chemical precipitation, incineration and compaction. The immobilisation phase includes any one or a combination of the following techniques: bitumen application, concretisation, polymerisation and vitrification.

The liquid HLW is immobilised in a stable matrix of borosilicate glass and stored before disposal in a geological repository. Glass, being amorphous, is preferred because it forms network with its oxygen and silicon atoms instead of crystals, which can be penetrated in cracks by radioactive substances.

Waste Recovery

The processing of Spent Nuclear Fuel (SNF) is much more complex and expensive than the preparation of the fuel for a nuclear application. Uranium and associated radioactive substances such as Plutonium are very expensive. In the processing of spent nuclear fuel, any minute quantity that can possibly be recovered is recuperated. *There are however three problems areas in its recovery.* These concerns are *first, the recovery of any left over Uranium-235, second, Plutonium extraction if produced, and third, the disposal of highly and largely useless products* (Atkins and Beran, 1990).

Uranium and Plutonium can be recuperated from SNF by solvent extraction (purex process): a process that makes use of their differing solubilities in various solvents. A composition of 80 % kerosene and 20 % triter-butyl-phosphate with water are used to process the spent fuel and to recuperate plutonium and uranium separately. Plutonium (IV) and Uranium (VI) oxides dissolve preferentially in the organic solvent while most of the other fission products dissolve in water. Plutonium (IV) is then reduced to Plutonium (III). Plutonium (III) and Uranium (VI) are mixed with water whereby Plutonium (III) oxide solution dissolves preferentially in the water. Further purification and reaction stages produce Uranium Oxide and Plutonium Oxide.

Storage and Disposal

The international scientific community is carrying out research to ascertain the most suitable ways of storing and disposing of nuclear and radioactive waste. While most of the LILW is being contained through near-surface disposal facilities and geologic repositories, the management and disposal of HLW still poses a threat to human life and the environment due to their long-lived radionuclides. Geological repositories are used as disposal systems for HLW and they tend to contain radioactivity within engineered barriers and natural barrier. Engineered barriers are human-made and they consist of multiple components, which includes solid waste, metal canister and clayey backfill material (most probably bentonite). Natural barrier is usually a thick geologic formation: granite rock, or some sedimentary impervious rock such as shale.

Some generators of SNF do not have the appropriate disposal facilities and may have to provide interim storage for up to ten years before exporting it to a country having the right facilities. The used fuel may be stored in facilities for up to one hundred years during which it must have been treated and conditioned for the appropriate decay period then disposed off in a geological repository.

Bredell and Fuchs (1997) propose an international waste management system whereby countries producing HLW and SNF can establish and share regional geological repositories for the disposal of their waste. It should be noted that currently there are no geological repositories for HLW and long-lived radionuclide waste. It is anticipated that by year 2010, the first ones will become operational and within the next twenty years thereafter, twenty additional similar systems would have become functional as well.

South African Situation

The Atomic Energy Corporation of South Africa was established in 1948 to undertake nuclear research and development. In 1965, SAFARI-1 (the nuclear research reactor) was in operation and by 1985, there were a couple or more Uranium enrichment plants in the country providing both weapons grade material and fuel for nuclear power stations. The AEC has directly or indirectly been involved in the manufacturing of over 200 products which are being marketed in South Africa and twenty other countries (AEC, 1998). With these on-going activities, radioactive waste is generated.

The National Radioactive Waste Disposal facility of the AEC, Vaalputs, is 120-km Southeast of Springbok. Only LILW from Koeberg nuclear power station in the Western Cape Province is processed and stored in near surface trenches (AEC, 1998). In a recent study on radioactive waste disposal carried out by Bredell and Fuchs (1997), it is projected that 322 960 tons of spent fuel will be generated in the world by 2010, of which 830 tons will come from South Africa.

Factors Affecting Radioactive Waste Management

National Policies

Although intergovernmental agencies and more particularly the International Atomic Energy Agency (IAEA) have set up regulations in the management of nuclear and radioactive waste, countries differ in approach in implementing these regulations. More than thirty one countries are listed in an inventory of SNF (Bredell and Fuchs, 1997), and the administration of their waste will some what differ in as much as a baseline on global safety is agreed by all the generators.

In the United States, the Department of Energy is mandated with the management of radioactive waste. It has technical challenges to overcome, which primarily are the construction of storage and disposal facilities and their management.

The plan considers the risk of transporting waste from one site to another, storing waste on-site, and ensuring worker safety while handling the waste. It works closely with the Environmental Protection Agency (EPA), United Nations, local governments, the military, academic and research institutions, concerned citizens, regulators and the public in the implementation of a national policy on nuclear and radioactive waste management. The South African government through the AEC is committed to establishing policies, programmes and practices for conducting operations in an environmentally sound manner.

Institutional Approach

Governments, NGOs and IGOs have different approaches to nuclear waste management. In 1996, the governments of Canada and Ontario commissioned Atomic Energy of Canada to evaluate the HLW disposal concept. The committee reported that socially, the public does not embrace this disposal system. More scientific tests have been carried out since then. The Alliance for Nuclear Accountability with its office in Washington DC has an affiliation of forty grassroots and national organisations working to address issues of nuclear weapons production and waste clean-up. It was founded in 1987 and concerns itself with:

- Public and worker health and safety;
- Environmental cleanup and restoration of contaminated nuclear weapons production sites;
- Dismantling and disarmament problems;
- Research, development and testing (actually experimenting); and
- Nuclear waste disposal.

The IAEA (Managing Radioactive Waste, 1998), plays a pivotal role in nuclear waste management. Primarily, the agency concentrates on the following:

- Collecting, reviewing and publishing up-to-date scientific and technical information;

- Providing direct services, particularly to developing Member States and the newly independent states of the former Soviet Union, through technical assistance, training, and other programmes to strengthen national infrastructures, including the demonstration of waste management techniques;

- Fostering and co-ordinating research and development through co-ordinated research programmes;

- Establishing safety standards for the management and disposal of waste by building international consensus;

- Implementing international codes of practice and safety conventions; and

- Providing a forum for the dissemination and exchange of information at international conferences, symposia and seminars including the promotion of education, public information and training; developing and implementing special projects, including assessment of the environmental and radiological impacts of waste disposal.

Economics

One of the main reasons why African countries have not developed nuclear capabilities is finance. Nuclear facilities including their waste are very expensive to manage. The US Department of Energy requested for three billion dollars in 1989 for the management of its nuclear waste. Between 1990 and 1994, the Department spent an additional seven hundred and forty six million dollars in constructing a waste isolation pilot plan. In 1995, it spent more than six hundred million dollars in the construction of underground storage tanks. The US Government has been collecting a levy to finance the disposal of nuclear waste and eleven billion dollars is earmarked!

South Africa can commit herself into some huge expenditure in Nuclear Technology. Other African countries will find it extremely difficult as they have to cope with hunger, health, unemployment, and education and civil strives. On the other hand, Western Powers may construct such facilities in Africa, if the need for imbalance of regional and global powers surface as a threat to the concerned nation.

Health and Social Factors

Radioactive substances are carcinogenic and the main type of cancer associated with it is lung cancer. Radium-226 and heavy metals such as magnesium and molybdenum leach into and contaminate groundwater at levels considered to be pollution. The use of plutonium in space operations has met serious emotional and emotive problems from the United States in particular.

Many native Americans working in mines producing radioactive substances have died of lung cancer. Others continue to suffer the effects of land and water contamination resulting from seepage, spills and tailings pile (UIC

Newsletter, 1995). South African gold mines extract large quantities of uranium as a secondary product thereby exposing neighbouring black communities to cancer-causing radium and radon that leak from uranium mine waste.

Environmental Factors

The environment has been artificially contaminated as a result of a number of manrelated activities. These activities include:

- ❑ Accidents such as the radioactive spill from Chernobyl nuclear reactor in 1986;
- ❑ Nuclear weapons production;
- ❑ Testing of nuclear weapons at some atolls;
- ❑ Nuclear energy generation and supply;
- ❑ Mining and milling;
- ❑ Poor radioactive waste management practices; and
- ❑ Abandoned radioactive facilities

The above-cited activities have not only contaminated but also caused marine, aquatic, terrestrial and air pollution. To this effect, the International Atomic Energy Agency (IAEA) conducted a symposium to review studies aimed at reconstructing radiation doses. Discussions were held under the "Precautionary Principle", which encourages precautionary measures to be taken in protecting the environment from potentially harmful contaminants even if there are no concrete evidence that those contaminants have an adverse effect. Studies have shown that global and regional release of radionuclides from dumpsites affect local environments.

Bain (1998) discusses the commitment of South Africa's AEC to the environment. In his discussion, it is mentioned that the AEC has always sought to improve its environmental management procedures. Currently affiliated to the International Chamber of Commerce (ICC), South Africa's AEC is a signatory of the Chamber's Charter for sustainable development safety, health and environmental aspects, and evaluates its compliance in terms of their environmental self-assessment programme. Recently, the South African corporation adopted a policy of zero effluent and release (AEC, 1998).

Safety

Generators of radioactive waste are concerned with individual and national safety. An argument may be raised regarding the international and national standards in the implementation of safety. Of past poor safety standards and human error have been the main cause of a number of accidents at nuclear reactor facilities and ocean vessels. A need emerged for an international body

to be responsible in formulating safety standards and procedures in the handling, treating, conditioning, storage and disposal.

IAEA has stepped into the shoe of regulating the safe management of radioactive waste. The Radioactive Waste Safety Standards (RADWASS) programme of the IAEA seeks to provide a series of documents in the fields of radioactive waste management, decontamination, decommissioning, and environmental restoration which is periodically reviewed by the International Radioactive Waste Management Advisory Committee (INWAC) (IAEA, 1994). There are about forty near-surface disposal facilities which have safely been operating for the past thirty five years, and thirty more related facilities will be added within the next decade (Managing radioactive waste, 1998). The IAEA operates its own nuclear research and service laboratories to support the safe and effective transfer of technologies to its member states. Their laboratories are based in Vienna and Seibersdorf in Austria, and Monaco.

Other Factors

Some other factors affecting the management of nuclear waste include research and development, availability of technical expertise and technological tools, aesthetics and legal/legislative implications. Some of these factors have been discussed in different sections of thischapter and need not be repeated.

Nuclear Waste Shipment

Not all generators of nuclear waste do have nuclear waste recovery facilities. Such institutional arrangements give vent to the need to have in place facilities to enable export of waste to be processed in waste recovery facilities in other countries. In 1992, Japan committed herself to return shipment of her nuclear waste presently to France. In January 1997 forty canisters containing twenty and a half million curies of radioactivity and weighing about twenty metric tons of reprocessed Japanese SNF was shipped from France. Other shipments had occurred prior to the 1997 lot that increased global concern for safety. One metric ton of weapons-usable Plutonium-239 was shipped from France to Japan through the Cape of Good Hope, Australia, New Zealand, and the Pacific Islands and to the final destination. In April 1995, a consignment of 28 logs of high level vitrified glass weighing about two hundred and fifty kilograms each, containing nuclear waste was shipped from France through the Atlantic to South America, Pacific, Hawaii and finally to its destination in the Aomori Prefecture in Japan. The same year, a consignment of SNF was shipped from Japan to France passing through the Panama Canal. It was estimated that there would be between one hundred and twenty to one thousand two hundred shipments by the end of the first decade of the new millennium according to

reactors are decreasing and there is on-going restoration of outused nuclear sites for other friendly purposes. Other countries are struggling to belong to the club of "Nuclear Power" states. Recently, India carried out three nuclear tests which was condemned by most of the nuclear powers of the western world and Japan. With on-going conflicts in the Middle East, many of those countries will likely develop their nuclear capabilities. In Africa, Nigeria may likely join South Africa in the "nuclear power club" which will force one of the African countries (most likely Cameroon) to develop her nuclear capabilities with the direct support of France.

On the other hand, scientists and institutions should be engaged in a two-fold research objective:

- To develop complex substances that can immediately counteract any effect of nuclear energy through military applications; and

- To develop new forms of applications that will advance the human-kind to the "cradle of technological civilisation". These activities will generate more waste.

Nuclear and radioactive technology will continue to find new applications in a number of areas, including the following:

- Soil fertility, irrigation and crop production;
- Plant breeding and genetics;
- Animal production and health;
- Insect and pest control;
- Agrochemicals and residues;
- Food preservation;
- Nuclear medicine;
- Radiation biology and radiotherapy;
- Radiation dosimetry;
- Nutrition and health;
- Research reactor support;
- Radiation engineering and technology;
- Control systems and radioactive tracers;
- Analytical techniques and quality control;
- Borehole logging and rock characterisation;
- Radioactively-labelled pharmaceuticals;
- Development of water and mineral resources; and
- Applications in chemical, oil production, steel, cement, automotives, and maritime industries.

New electrical generation from wind is beginning to exceed that from nuclear power (Barnard and Terreblanche, 1998). Modern information technology

the operating Japanese-French contract towards the beginning of the new millennium (Van Dyke, 1998).

As at the end of 1997, radioactive waste was being shipped for reprocessing in accordance with Japanese and French venture cited. Brendell and Fuchs (1997) suggest establishing regional repositories. The implication of this move would mean more shipments of radioactive waste to their reprocessing and recycling, and storage destinations. International institutions and national governments would have to enforce stringent safety factors so as to avoid accidents in the course of transportation.

The Battlefield

Countries and corporations have been exploiting the loophole of the "Precautionary Principle" in transporting their nuclear waste. The Precautionary Principle also known as Principle 15 of the 1992 Rio Declaration on Environment and Development states that:

> *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Whereby there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"*
> (Agenda 21, 1992).

On the other hand, nations have the right under international law to block passage through their maritime waters of an ultra-hazardous transport (Van Dyke, 1998). Countries that are used for passage of nuclear waste could use force to divert the course of a freighter. An example is the Chilean gunboat, which forced a British nuclear waste freighter to change course and leave Chilean maritime territory. According to Van Dyke (1988), there is need therefore to create an international set of rules to govern the transportation of ultra-hazardous substances (which includes nuclear and radioactive substances). Such rules and regulations will accommodate countries that generate the waste, those that process and recycle the waste, and also those whose maritime waters are used for passage.

The Way Ahead

On a global perspective, the quantity being generated of nuclear and radioactive waste is on the increase. Many more military weapons are being dismantled. Presently, there is no economically, environmentally, and politically acceptable way long-term storage of radioactive waste containing plutonium-239 hundreds of thousands of years (Miller, 1996). The numbers of nuclear

facilities make nuclear technology knowledge to be easily accessible. The future in the use and types of applications of nuclear technology rests in the hands of the world leaders, the politics and economics of globalisation, and the sanity of minds of those in authorities worldwide.

Conclusion

This chapter has reviewed the management of nuclear and radioactive waste. Although 22% of world uranium production comes from Africa, the continental waste is not up to 1% of the HLW generated worldwide. Statistics could not be referred to for other forms of radioactive waste production in the continent. It has considered the African situation and argues more from an economic perspective why the continent lacks these facilities. South Africa however stands alone in the application of nuclear technology in the Africa.

The activities and commitment of IAEA regarding nuclear and radioactive waste management are recognised, and it is anticipated that through their research endeavours (collaboratively with other national, international and private institutions of like objectives), more man and environmentally friendly applications will be developed and implemented. Nuclear and radioactive waste contains radionuclides that are long-lived with intense radioactivity. Its disposal is a problem that concerns this generation and affects posterity. We have an obligation to leave our planet cleaner than we found it.

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