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Characterization of Radioactive Waste for the PBMR Fuel Plant

M.E. Makgae
PBMR (Pty) Ltd, Fuel Group, Lake Buena Vista Building, 1267 Gordon Hood Avenue, Centurion, 0046

Z.N Hlatshwayo
PBMR (Pty) Ltd, Fuel Group, Lake Buena Vista Building, 1267 Gordon Hood Avenue, Centurion, 0046

ABSTRACT
The Pebble Bed Modular Reactor Pilot Fuel Plant which will built in North West Province, South Africa will produce various types and classes of wastes. Some of the waste will be contaminated with uranium rendering them radioactive. Although the radioactive waste will be classified as Low and Intermediate Level waste, This paper defines how PBMR Pilot Fuel Plant is going to characterize the radioactive waste generated by determining the physical, chemical and radiological properties of waste to establish the need for further adjustment, treatment, conditioning or its suitability for further handling, processing, storage or disposal. The techniques applicable in this characterization process are x-ray spectrometry, ion beam analysis, gamma spectroscopy, alpha spectroscopy and nuclear micro-analysis. These techniques will ensure that waste classification is according to IAEA expectations and national regulatory requirements.

INTRODUCTION
The initial fuel loads for to the PBMR (Pty) Ltd Pebble Bed Modular Reactor will be manufactured in a Pilot Fuel Plant (PFP) located on the Nuclear Energy Commission of South Africa (Necsa) site. This site is located in the North West Province, Madibeng Municipal Authority. The fuel, manufactured by relatively complex chemical processes, will be enriched uranium oxide The fuel is in the form of individual spheres of 60 mm diameter. Within each sphere there are approximately 15,000 uranium oxide particles. These have been coated, during the manufacturing process, with various layers of graphite and a silicon layer. The particles are embedded in a fuel sphere matrix. Each particle has, at its center, a 0.5mm diameter enriched uranium oxide kernel. During the manufacture of the fuel there will be various waste streams, some of which will be radioactive. There will be contaminated gases, solids, and liquids, the radioactive contaminant being enriched uranium oxide and its associated daughter products.

The plant will be operated by the PBMR (Pty) Ltd, Fuel Division.

This paper focuses on the waste characterisation processes that will be utilized by the PBMR (Pty) Ltd, Fuel Division and on the approach to be adopted to manage radioactive waste.

TYPES OF RADIOACTIVE WASTE
There are several processes in the PFP that will generate different types and classes of radioactive waste. These will include waste arising from kernel production, kernel coating, fuel sphere pressing, process materials and general uranium recovery. The waste expected to be produced is predominantly uranium contaminated radioactive waste, in the form of solids, liquids and gases.

At the outset of the nuclear age, the operational focus was centered more on the activities that generate nuclear waste rather than on the characteristics of the wastes generated or on the disposal of those wastes and their resultant impact on the environment and the public. The first waste classes were based primarily on operational and handling concerns (physical form, radioactivity, heat generation rates, and exposure rates) or on the process that produced the waste. As there was limited disposal off site, the impacts of disposal on public health was seen to be minimal. However, as the industry matured the management of waste, particularly radioactive waste has become integral to the overall safety and environmental strategy of any licensed fuel manufacturing facility.

Emissions/ Gaseous Waste
All releases of gaseous waste will be controlled. The PFP process units will be serviced by a heating, ventilation and air conditioning system (HVAC) that will ensure that extraction of gaseous wastes are expelled to atmosphere via pre-filters and high efficiency particulate air filters (HEPA). These will

contribute to ensuring that all gaseous emissions meet regulatory requirements and that radiological risks are as low as reasonably achievable.

Solid Waste
Solid radioactive wastes generated during normal operation, upset conditions and decommissioning of the PFP will consist of:

- ion exchange resins and filter materials used in the PFP facilities (compressible and non-compressible);
- over shoe covers, cleaning cloths, paper towels, etc., used in areas where radioactive material is present,
- containers, cloth, paper, fluids, and equipment which come in contact with radioactive material;
- unserviceable contaminated Structure, Systems and Components (SSC) like hand tools, components, mechanical plant components; and
- residue from decontamination activities.

Effluent/ Liquid Waste
Liquid wastes, generated during PFP operations, will be pumped to the PFP effluent treatment facility. After treatment, waste will be discharged to the environment, if it meets the criteria laid down by Department of Water Affairs and Forestry (DWAF), Department of Environmental Affairs & Tourism (DEAT) and clearance levels stipulated by National Nuclear Regulator (NNR). Alternatively, an option under investigation is to use the Necsa site effluent treatment facilities. In this instance discharges to the environment will comply with the Necsa site's Effluent Discharge Permit in compliance with DWAF and NNR requirements.

The effluent treatment facility is designed to recycle liquid waste for reuse, e.g. dilution of effluent, supply to the batch plant for solid waste processing or supply to the decontamination system where water is required in these processes.

The envisaged liquid waste processing involves chemical treatments (e.g. for pH correction, conversion of chemical substances etc.), recirculation, radioactive treatment, and dilution with non-active waste to achieve an effluent quality acceptable for environmental discharge.

STRATEGY FOR SOLID AND LIQUID WASTE

The Constitution of Republic of South Africa (Act 108 of 1996) states that the people have the right to an environment that is not detrimental to human health. PBMR (Pty) Ltd fully subscribes to this statement and is the process of planning and drafting several plans and strategies to ensure that all impacts associated with its activities are minimized and mitigated against. One of these is the Waste Management Plan that is in line with legal and other requirements. The Waste Management Plan is a comprehensive plan that integrates all management activities related to waste from the plant. ? in your Sept. paper you call this the Radioactive Waste Management Plan…….? Be consistent, what do you want to call it? Also see top of Criteria section .

The overall objective of waste management in PBMR PFP is to ensure that all PFP wastes are managed appropriately capitalising on processes that minimise, reduce, recover and recycle without exposing employees, the public and the environment to unmitigated impacts. The intention is to manage radioactive waste in a safe and transparent manner, compatible with international and national principles [IAEA, 1995] [DME, 2005] and standards.

The PBMR (Pty) Ltd fully embraces the principle of "cradle to grave" waste management. This will include waste generation prevention, handling including minimization, reduction, recycling and treatment efficiency (Transportation and final disposal of waste will be sub contracted). This would ensure waste management which focuses on waste prevention and waste minimization as illustrated in Figure 1.

Waste Hierarchy	
Cleaner Production	Prevention
	Minimisation
Recycling	Reuse
	Recovery
Treatment	Physical
	Chemical
	Destruction
Disposal	Disposal/ Storage

Figure 1: Steps in Waste Hierarchy (DEAT 1999)

The overarching waste management strategy of the PFP is as follows:

- Prevention of waste generation: The plant design includes processes for optimisation and prevention of generation of waste.
- Waste minimisation: The design of the plant includes processes to minimise the generation of wastes e.g. regeneration of chemicals for recycling and treatment of effluent and emissions before discharge to the environment.
- Waste recovery: Waste treatment activities e.g. decontamination and mechanisms to clear waste for reuse, recycling and disposal. The plant design includes processes for recovery of uranium and recovery of hazardous chemicals for reuse in processes.
- Waste treatment and disposal: The waste streams from the plant will be categorised and classified according to the combination of relevant properties such as waste form and radioactivity (PBMR, 2002).

CRITERIA FOR WASTE CLASSIFICATION

The development of the radioactive waste management plan is being governed by several international good practices and national legislation. International expectations from IAEA have been integrated into national legislation ensuring that whilst complying with South African legal requirements nuclear projects are aligned with international expectations.

The management of radioactive waste in South Africa is regulated by the NNR in cooperation with other regulatory bodies like DEAT and DWAF. According to the Regulations in terms of the NNR Act 1999 (published in April 2006), one of the requirements from a licensee is to establish a radioactive waste management programme (is this different from the plan?? If not keep the same). This programme should be aimed at

- controlling the generation of waste;
- identification, quantification, characterisation and classification of all radioactive waste generated;
- provision for the treatment and other waste management steps leading to authorised discharge, disposal, reuse or recycling; and
- provision for the safe storage of radioactive waste between any waste management processes.

Radioactive waste is classified as shown in Table 1 below.

IAEA and DME **waste** classes	Waste Criteria
High Level Waste (HLW)	**1. Thermal power of 2kW/m^3 Long lived radionuclide concentrations exceeding for short lived waste. OR** **2. Long lived alpha, beta & gamma emitting radio nuclides at activity levels > levels specified for LILW-LL. OR** **3. Long lived alpha, beta & gamma levels that could result in inherent intrusion dose above 100mSv per annum.**
Low & Intermediate Level Waste-Long Lived (LILW-LL)	**1. Thermal power (mainly due to short-lived radio nuclides < 2kW/m^3. OR** **2. Long lived radionuclide concentrations** • **Alpha: <4000Bq/g** • **Beta & gamma: <4000Bq/g. OR** **3. Long lived alpha, beta and gamma emitting radio nuclides at activity concentration levels that could result in inherent intrusion dose between 10 and 100 mSv per annum**
Low & Intermediate Level Waste-Short Lived (LILW-SL)	**1. Thermal power mainly due to short lived radio nuclides <2kW/m^3. OR** **2. Long lived radio nuclides concentrations** • **Alpha: <4000Bq/g** • **Beta & gamma: <4000Bq/g. OR** **3. Long lived alpha, beta and gamma emitting radio nuclides at activity concentration levels that could result in inherent intrusion dose below 10 mSv per annum**
Exempt Waste (EW) (IAEA, 1994) or Very Low Level Waste (VLLW) (DME,2005)	**1. 0.1Bq/g – 10^{4}Bq/g. OR** **2. Annual doses of 0.01mSv. OR** **3. Authorised or clearance discharge**

Table 1: Waste classes according to the Department of Mineral and Energy (DME) and *the International Atomic Energy Agency (IAEA)*

CHARACTERISATION OF RADIOACTIVE WASTE

Only low level waste will be generated by the PFP. Waste will be characterized by determining physical, chemical and radiological properties

This will be used to establish the need for further adjustment, treatment, conditioning, or suitability for further handling, processing, storage or disposal.

Waste from the PFP plant will be characterised at various process stages. This is to obtain information on its properties and also to:

- assist in monitoring the quality of the fuel products,
- verify the production process and
- facilitate final safe processing and disposal of radioactive waste.

This will be achieved through sampling and analysis of the chemical, physical and radiological properties of wastes. This will be supported by indirect methods of characterization based on process control and process knowledge.

Radiological Characterisation

Radiological characterization of wastes will be carried out to determine the presence of individual radio nuclides and quantifying their inventories. This will be done using a variety of techniques, depending on the waste form, radio nuclides involved and level of detail required.

A radiation dose rate measurement will give an indication of the total quantities of beta-gamma emitting radio nuclides in a waste package. This will not identify individual radio nuclides or their concentrations. However, gamma spectroscopy will be used to identify individual radio nuclides and their quantities. ~~as well~~. Other techniques, such as active/passive neutron interrogation, alpha spectroscopy, and liquid scintillation counting will be used to assess other classes of radio nuclides. These methods will be "non-destructive" or "non-invasive".

Chemical Characterisation

Chemical characterization of waste will be applied to determine the chemical composition and properties of the waste. This will be done by waste sample, and chemical analysis.

Radiological and chemical waste characterisation can be supported from process knowledge and flow sheet data. For example, within the Research and Development (R&D) department of the Fuel Division, under controlled experimental conditions, fuel spheres are produced. This enables the PFP's process flow sheets to be verified and hence assess from the "knowledge of the process" which radionuclide(s) and/or chemicals will be present in waste streams.

Physical Characterisation
Physical characterisation will involve inspection of the waste to determine its physical form, strength, etc. Inspection of closed waste packages will be done using a variety of techniques, such as radiography (X-ray) and sonar.

From the assessments, using these characterization techniques, an informed decision can be made to on the most appropriate waste management strategy for a waste stream.

PILOT FUEL PLANT WASTE MANAGEMENT

As noted, and expanding further, the specific objectives for the PFP's waste management are as follows:

- To ensure that all releases into the environment are within legal limits. This will be done by ensuring that the design and operation of the plant meets legal limits as a minimum.
- To ensure that waste handling, treatment and disposal does not result in undue radiation exposures to employees, the public and the environment.
- To ensure, before the disposal option, that strategies have been assessed to prevent, minimise, reduce, recycle, recover and treat waste.
- To ensure a system of accounting and tracking of radioactive waste from the PFP is in place as a waste information system with an implementation, sampling, surveillance and monitoring plan
- To integrate the principle of continual improvement into all plant processes that generates waste.
- To ensure that training on, and awareness of, waste management is implemented for all employees

Solid Waste Management
All solid wastes from the plant will go through a process of classification in terms of level of radioactive contamination. Waste that is not contaminated in any way will be disposed of at an authorized landfill as general waste. Waste. with radioactive contamination above certain levels will be taken to the PFP Uranium Recovery Facility to recover uranium. The uranium recovered from this facility will be fed back into the process.

Where uranium recovery is not feasible, the waste will be sorted prior to packing in drums. The waste will be sorted according to whether it can be compacted to not. Compactable solid waste will be compacted and packed in steel drums. It is expected that PFP waste will be classified as LILW.

The plant will have equipment for handling waste during the filling, compacting and drum sealing process. Equipment for moving the drums from their filling position to the storage area will be available. This equipment will be in place to contribute to minimize occupational exposure of employees during handling operations.

Liquid Waste Management
Liquid radioactive waste from plant processes will be piped to the PFP Effluent Treatment Facility. Most of the chemical component of the waste can be recovered for re-use in the various plant processes after the radioactivity level are reduced by treatment. The waste will be treated according to specification required by the regulators (DWAF, NNR and DEAT) Are these all regulators ??? or just Departments of State.. Waste will then be released to the Necsa treatment system for further treatment and/or independent analysis and final disposal to the environment.

CONCLUSION

Typically, the PFP will produce the LILW which will be primarily uranium and its associated daughter products. All wastes will be managed in such a manner to be aligned to the PFP's commitment to ensuring the protection of the operator, environment and the public by waste minimisation. Good practices in environmental management and nuclear safety that will be clearly reflected in the PFP radioactive waste management plan.

Characterization of waste has been identified as a key element in contributing to ensuring that the PBMR (Pty) Ltd waste management strategies are developed and implemented. The characterization techniques that will be adopted have been researched to identify the most appropriate and relevant, given the chemical inputs that will be used for the PFP fuel production processes. The techniques will assist in ensuring that waste is minimized and recycled resulting in a reduced radiological impact on the public, operator and environment.

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