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Environmental Radiological Monitoring Program for Uganda's First Nuclear Power Programme: A Proposal for its Establishment

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1. Introduction

The operation of a nuclear power plant (NPP) inevitably results in the controlled release of radionuclides to the atmospheric and aquatic environment. Therefore, the environmental radiological monitoring program (ERMP) should be established in order to demonstrate compliance with authorized discharge limits and any other regulatory requirements [1]. The most important thing of all is to protect the public health and the environment from undue radiation hazards from a nuclear installation. Uganda is embarking on a new nuclear power programme that requires establishing sustainable infrastructure including environmental protection (EP). The EP encompasses various activities such as environmental radiological monitoring [2].

There are different types of ERMPs which depend on the stages of NPP such as pre-operational, operational, and decommissioning, but the competent regulatory authority must give the guidelines for their implementation and approve them.

This study aims to prepare the guidelines for establishment of the ERMP for Uganda's first nuclear power programme, which includes a legal and regulatory framework, and the design of a comprehensive ERMP aligned with the IAEA safety standards.

2. Materials and Results

2.1 Status of Nuclear Power Programme in Uganda

Uganda plans to develop NPPs with a total output of 24,000 MW, establish research reactor centre, and uranium exploration is ongoing in the country with the aim of discovering uranium deposits for a sustainable nuclear fuel supply [3]. Current studies reveal 08 potential NPP sites identified in the districts of Kiruhura, Kassanda, Nakasongola, Buyende, and Lamwo (see Fig.1). Accordingly, Buyende is likely to host the first NPP, anticipated to be operational by 2031, as outlined in the National Development Plan III. The Buyende NPP would be constructed roughly 150 km north of the Kampala capital city, as shown in Fig.1. The ministry of Energy and Mineral Development (MEMD) of the Uganda government signed a memorandum of understanding (MOU) with Korea Hydro & Nuclear Power Co., Ltd.(KHNP) to cooperate in training, education, research including building technology of the Advanced Power Reactor 1400 (APR1400) [4]. The APR 1400 is a 4000-MWt pressurized-water reactor (PWR) that generates 1400 MWe of electricity per unit [5].

Fig. 1. Uganda's map showing district locations for potential NPP sites

2.2 Framework for Environmental Protection in Uganda

In 2008, Uganda enacted the Atomic Energy Act (AEA), which provides for regulation of peaceful applications of ionizing radiation, and includes provisions for the development of nuclear energy for power generation. The Uganda framework for environmental protection (radiological) consists of the National Environment Act, 2019 (NEA), and the AEA (illustrated in Fig.2). The National Environment Management Authority (NEMA), established under the NEA No.5, as the principal environmental regulator, is responsible for regulating, monitoring, supervising and coordinating all activities relating to the environment which also include implementation of a nuclear power program. The Atomic Energy Council (AEC), was established under the AEA No.24, as the national atomic energy regulator, responsible for protecting people and the environment from radiation hazards. The AEC has MOU with the Korea Institute of Nuclear Safety (KINS) in the area of capacity building. The Atomic Energy Regulations (AER), 2012, made under section 73 of the AEA, require an authorized person (operator) to set up an adequate environmental monitoring programme according to requirement 78 (2)(e), in order to control and, account for discharge or release of radioactive substances to the environment.

In line with section 108 of NEA and section 74 of AEA, standards, guidelines and criteria in regard to radiological environmental protection should be established based on the MOU between NEMA the AEC.

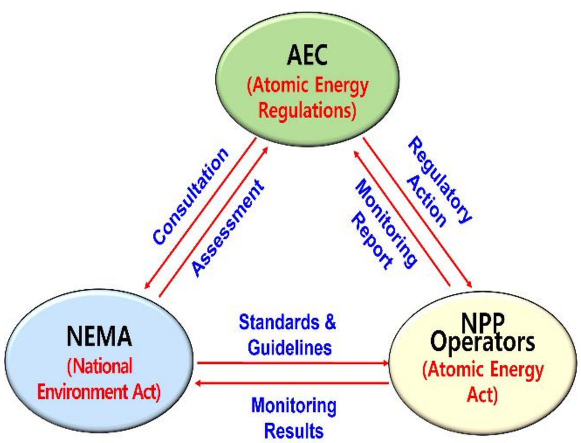

Fig. 2. Regulatory framework for environmental radiological monitoring

In addition, the NEMA is required to guide the Strategic Environmental Assessment (SEA) process and approve the Environmental Impact Assessment (EIA) studies with regard to nuclear power, in line with the National Environment (SEA) regulations, 2020, and, (Environmental, and Social Assessment) regulations, 2020. The AEC should have the capabilities to monitor and control environmental radioactivity arising from nuclear facility to verify compliance as outlined in the introduction.

As mentioned before, NPP operators in Uganda will be responsible for designing and implementing the ERMP in accordance with requirement 78 of the AER, while the AEC will be responsible for reviewing and ultimately authorizing the ERMP. Therefore, the AEC needs to provide guidance on how to design the ERMP.

2.3 Radionuclides potentially released to the environment during NPP normal operation

During NPP normal operation, controlled amounts of radionuclides are released to the atmospheric and aquatic environment in gaseous and liquid effluents [6]. The radionuclides and quantities released differ by the reactor type, the fuel cycle, and the release pathways, but are generally classified as fission products (FP), activation products (AP), and transuranic elements (TRU) according to origin of production. For FPs, more than 200 radionuclides are produced by fission reaction of U or Pu and most of FPs are radioactive; beta minus decay, and gamma emitters. However, monitoring target nuclides are relatively high fission yield and more than a few minutes of half-life in terms of radiation safety. Table 1 shows some radionuclides that are very important from a monitoring perspective.

Table 1: Some monitoring target radionuclides from FPs

Radionuclides		Half life	Fission yield (%)
Noble gases	^{85}Kr	10.752 Y	1.310
	^{133}Xe	5.243 D	6.60
Iodine	^{131}I	8.023 D	2.878
Particulates	^{90}Sr	28.80 Y	5.73
	^{95}Zr	64.032 D	6.502
	^{106}Ru	1.018 Y	0.410
	^{137}Cs	30.05 Y	6.221
	^{140}Ba	12.753 D	6.315
	^{144}Ce	285.1 D	5.475

[Note] All fission yields taken from IAEA/INDC and represent ^{235}U chain fission yields for thermal neutron

APs are produced when a neutron is captured by the materials such as fuel cladding, structural components of reactor, coolant, control rods or other neutron poisons, shielding, etc. Most of APs are also radioactive; beta minus decay, and gamma emitters. Table 2 shows some radionuclides that are produced by activation of some materials for PWR NPPs.

TRUs such as ^{238}Pu, ^{239}Pu, ^{241}Am, ^{244}Cm, etc. are present in the reactor due to a nuclear reaction caused by the absorption of neutrons of ^{238}U in the nuclear fuel or nuclear decay process.

Tritium(^{3}H) is produced in significant quantities by the nuclear reaction of $^{6}Li(n,a)^{3}H$, $^{7}Li(n,2a)^{3}H$, and $^{10}B(n,2a)^{3}H$. Litium (LiOH) is used as a pH control of coolant and Boron (H_3BO_3) is used a neutron poison. Also, ^{3}H is produced by ternary fission of nuclear fuel.

Table 2: The principal radionuclides formed by activation reactions in PWR NPPs

Radionuclides	Half life	Nuclear Reaction	Activation Materials
^{95}Zr ^{65}Zn	64.032 D 243.86 D	$^{94}Zr(n, \gamma)^{95}Zr$ $^{64}Zn(n, \gamma)^{65}Zn$	Fuel cladding (Zircaloy: Zr-98%, Sn-1.5%, Fe, Cr, Ni)
^{58}Co ^{51}Cr ^{59}Fe ^{56}Mn	70.86 D 27.71 D 44.49 D 0.107 D	$^{58}Ni(n, p)^{58}Co$ $^{50}Cr(n, \gamma)^{51}Cr$ $^{58}Fe(n, \gamma)^{59}Fe$ $^{55}Mn(n, \gamma)^{56}Mn$	Steam Generator(fine tubes) (Inconel Alloy: Ni-70%, Cr-15%, Fe-8%, Mn)
^{60}Co ^{51}Cr	5.26 Y 27.71 D	$^{59}Co(n, \gamma)^{60}Co$ $^{50}Cr(n, \gamma)^{51}Cr$	Control rods, Valve, Bearing of Pump, etc.. (Cobalt Alloy: Co-45%, Cr-30%, C-2.5%, W)
^{54}Mn ^{51}Cr ^{58}Co	312.29 D 27.71 D 70.86 D	$^{54}Fe(n, p)^{54}Mn$ $^{50}Cr(n, \gamma)^{51}Cr$ $^{58}Ni(n, p)^{58}Co$	Piping Components (Stainless Steel: Fe-70%, Cr-18%, Ni-11%)
^{16}N	7.13 S	$^{16}O(n, p)^{16}N$,	Reactor Coolant (H_2O)

2.4 Design of the Environmental Radiological Monitoring Program(ERMP)

The ERMP is a highly valuable tool to demonstrate that the public and the environment are protected from radiation hazards related to the NPP operations. Whereas authorized persons (NPP operators) should establish and implement an adequate program for environmental monitoring as highlighted in section 2.2 above and report the results accordingly, the AEC should be responsible for verifying compliance, and informing the public on the extent of radiation exposure. Therefore, the AEC is required to implement an independent ERMP, separately from NPP operators to align with requirement 32 of IAEA/GSR Part 3 [7].

The ERMP should be designed using a systematic approach, and a graded approach for monitoring activities. The ERMP also should take into account several features of the NPP site environment to be monitored;

(a) geology, hydrology, meteorology, geomorphology.
(b) population, occupation, living habits and conditions.
(c) land and water use, agriculture, food production.
(d) other industrial and economic activities, etc..

Considering Buyende District in Uganda; it is flat in a rough way and adjacent to Lake Kyoga, with a total area of 1885 km^2 , of which 725 km^2 is occupied by water. Most of the residents are engaged in agriculture with fishing at Lake Kyoga. The predominant wind direction of Buyende District is SSW with the average wind speed of 1.47 m/sec [4]. In case of the deployment of the first NPP in Buyende District, the ERMP should be designed and implemented with the primary considerations of water use from Lake Kyoga in view point of domestic consumption and agricultural water.

For monitoring of external radiation levels in inhabited areas, the ambient dose rate should be measured in typical areas that are accessible to the public, such as dwellings, public buildings, production areas, gardens and recreation areas such as parks and beaches.

The ERMP should provide the following information;

(a) radionuclides to be monitored
(b) environmental media to be sampled
(e.g. air, soil, water, biota, foodstuffs, etc.)
(c) sampling locations and frequency
(d) sampling methods and criteria
(e) sample handling and preparation
(f) measurement and laboratory analysis
(g) detection limits
(h) quality assurance and control, etc.

The results of the ERMP should enable the verification of the predicted doses to the public using dispersion models and data from source or discharge monitoring. For this purpose, the environmental media and radionuclides should be selected on the basis of the dispersion pattern of the discharges and on the relevant exposure pathways (illustrated in Fig.3).

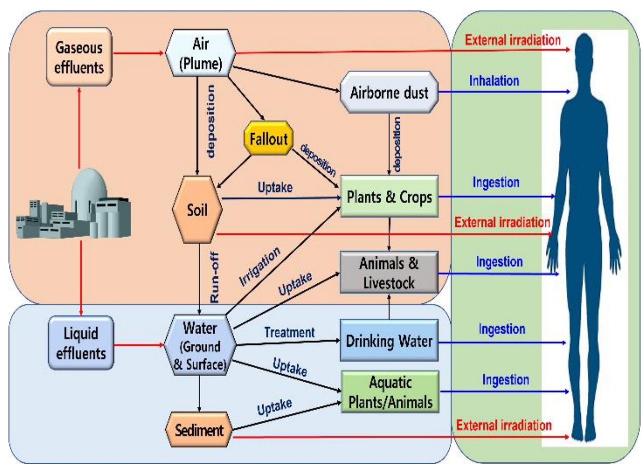

Fig. 3. The Possible exposure pathways for the public

Furthermore, the sampling of food products should be determined on the basis of knowledge of the habits and consumption patterns of the representative person.

Basically, the NPP operator has the responsibility for pre-operational monitoring to establish baseline environmental radiation levels and radioactivity concentrations for the purpose of determining the subsequent impacts of sources or discharges. The pre-operational ERMP should take account of the types and amounts of radionuclides that might be discharged during the operation of the NPP, and the possible exposure pathways. According to the IAEA Safety Reports Series No. 64 [6], the pre-operational ERMP should be implemented at least two-three years before the NPP goes into normal operation. In both monitoring phases, the monitoring programs are almost similar and ideally the sampling points should be identical locations in order to compare results of both stages.

An analysis plan put forth, should be supported by a radio-analytical laboratory network (shown in Fig.4) to perform sample preparation and measurements, and field measurement stations at designated locations. The choice of analysis technique such as β, α, and γ spectroscopy should depend on sample media and radionuclides of interest as should be deemed as suitable indicators [8].

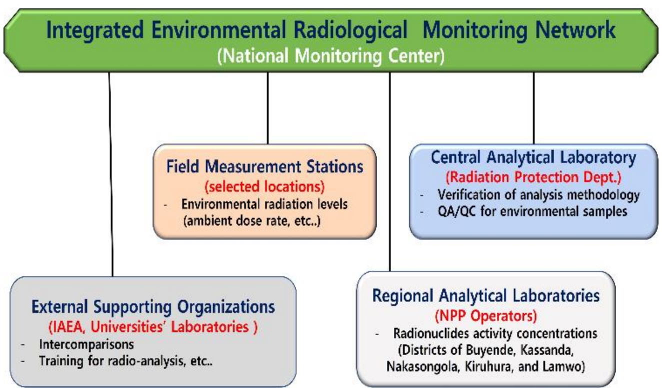

Fig.4 Proposed environmental radiological monitoring network for NPPs

3. Conclusions

In this study, general considerations of the ERMP for Uganda's first nuclear power programme was presented to provide guidance on how to design the ERMP. The ERMP should be designed including the rationale for the environmental media to be sampled, sampling locations, sampling strategy and analytical methods. The monitoring program should also provide information on procedures for managing and interpreting the data, assessing data quality, and reporting the results. Particularly, the quality assurance and control including uncertainties should be implemented to ensure the EMRP's validity. In addition, the design of the ERMP should be reviewed periodically and revised reflecting the stages of NPP such as pre-operational, operational, and decommissioning stage. In case of the deployment of the first NPP in Buyende District, the ERMP should be designed and implemented with the primary considerations of water use from Lake Kyoga in view point of domestic consumption and agricultural water.

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