Preliminary Study of Radiological Environmental Impact Assessment for 5MW Nuclear Research Reactor in Kenya

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1. Introduction

The government of Kenya plans to construct a 5 MW nuclear research reactor which can in future be expanded to 10 MW. The research reactor will have many possible uses in line with the country's development goals and will offer important economic benefits. A research reactor has the potential to offer affordable radiotherapy and radio-diagnosis services in Kenya through the production of radioisotopes which could be used in the country and also be traded with neighbouring countries in the region. A research reactor also has many possible uses: in the agricultural sector, it could give perishables a longer shelf-life accordingly increasing food security and in the manufacturing industry, the doping of silicon makes it greatly conductive of electricity.

The Kenyan government through the Nuclear Power and Energy Agency (NUPEA) is undertaking a feasibility study for the construction of a nuclear research reactor. There are three sequential phases in the development of infrastructure to support the building of a research reactor. Kenya is at infrastructure milestone one. Part of the pre-project activities involve conducting an environmental impact assessment. This addresses the impact of small releases of gaseous and liquid effluents during the normal operation of the research reactor to people and the environment. Information on food consumption of the Kenyan population is used in the estimation of exposure to radioactive material that may be found in the food chain following release of liquid and gaseous effluents during normal operation. However, although mean food consumption data exists for the Kenyan population, age specific information on food consumption data is not provided.

This research paper focuses on a criterion for estimating age specific food consumption data, conducting and presenting a pre-radiological environmental impact assessment using the KINS-INDAC code. On the basis of this code, it then provides a report considering reactor processes on a single site. The KINS-INDAC code provides a large number of output data but this paper estimates the maximum and mean effective dose to various age groups living within and beyond the Exclusion Area Boundary (EAB). The results of this study will then be compared to identified suitable dose criteria.

The results and experience gained from this research will be valuable in enhancing and clarifying a framework of operation for the Kenya Nuclear Regulatory Authority and relevant authorities in relation to environmental laws, regulations and responsibilities. Data obtained could also be used for public communication in the future.

2. Methods and Results

This section describes methods used to collect and prepare information for conducting a Radiological Environmental Impact Assessment. Meteorological data and annual food consumption rate intake will be used for analysis. However, meteorological data is not prepared in this study and will be prepared through further study.

2.1 Age- specific group model

The selection of age groups used for this analysis are based on ICRP recommendations used to determine compliance with dose constraints. Two sets of age groups are chosen for this analysis. The first age set is based on *ICRP-60, 1990* [1] and consists of 6 age groups. The second age set is based on *ICRP-101,2006* [2] and consists of 3 age groups. The ICRP states that with the exception of exposure to actinides, the difference in exposure to different age-groups is limited [1]. It is for this reason that, the consumption is assessd in groups and each age is not considered on its own.

2.2 Annual food consumption intake rate data

The food groups used for analysis in this research include plant products, animal products and finally aquatic products as shown in Table 1,2 and 3 respectively. The average amount of food consumed was obtained from *Kenya National Bureau of Statistics* food balance sheets 2014-2018 [3].

Table 1: Food intake rate of plants [kg/year]

Mean Intake (kg/year)	Cereals	Maize	Vegetables	Fruits	Rice
	135.0	69.5	41.8	70.5	20.6

Table 2: Food intake rate of animals [kg/year]

Mean Intake (kg/year)	Bovine	Sheep &Goat	Poultry	Pig	Milk
	14.0	1.1	2.6	0.4	93.3

Table 3: Aquatic fish intake rate [kg/year]

Mean Intake (kg/year)	Freshwater Fish	Marine Fish	Pelagic Fish
	3.1	0.5	0.4

2.3 Derivation of age specific correction factor

Age specific food consumption intake rate data for different food categories is not available in the food balance sheet for Kenya. As a result, the best publicly available data for estimation of age specific food consumption per individual are obtained from EPA's *Exposure Factors Handbook* [4]. Approximately 20,000 individuals were monitored for 2 non-consecutive days based on a 24 hour diet. Using this data, correction factors for estimation of age specific ratio for various food categories and age groups were calculated as shown in Equation 1 [6]. The results were then presented for two different age sets; one age set based on *ICRP-60* [1] and the other based on *ICRP-101* [2] as shown in Table 4.

The mean per capita intake rate values are obtained from EPA's handbook and the total population mean per capita intake rates are obtained by adding the mean per capita intake rates. The mean per capita intake rates are useful for estimation of exposure because, they take into account longer time frames, geographic location, degree of urbanization and social economic characteristic among other factors.

$$Correction\ Factor\ (C.F) = \frac{Age - Specific\ mean\ per\ capita\ total\ intake\ (\frac{g}{day})}{Total\ Population\ mean\ per\ capita\ total\ intake\ (\frac{g}{day})} \quad \textbf{(1)}$$

The following assumptions were made:

i. Total grains including; cereals, maize and rice have a single common correction factor.
ii. Total meats including; bovine (beef), poultry, pig, fish, sheep and goats also have a common correction factor.

Table 4: Age-specific correction factor derived from the ratio of age specific intake rate to total population intake rate.

	Total Grains Cereals, Maize, Rice		Vegetables		Fruits		Total Meat Beef, Pig, Poultry, Fish Sheep and Goat		Milk	
Age Set 1 (6 Age Groups)										
	Intake	C.F	Intake	C.F	Intake	C.F	Intake	C.F	Intake	C.F
Total Pop	**141.65**	**1.00**	**165.3**	**1.00**	**91.9**	**1.00**	**112.6**	**1.00**	**310.7**	**1.00**
0-1 years	23.6	0.17	41.0	0.25	50.8	0.55	11.2	0.10	90.9	0.29
1 to <2 years	72.7	0.51	75.8	0.46	106.0	1.15	44.9	0.40	556.1	1.79
2 to <7 years	104.1	0.73	92.9	0.56	103.9	1.13	68.1	0.60	446.8	1.44
7 to <12 years	147.6	1.04	120.2	0.73	95.4	1.04	95.1	0.84	437.3	1.41
12 to <17 years	155.1	1.09	136.3	0.82	73.8	0.80	121.0	1.07	385.7	1.24
more than17 years	155.9	1.10	200.1	1.21	95.5	1.04	130.7	1.16	266.6	0.86
Age Set 2 (3 Age Groups)										
Total Pop	**141.65**	**1.0**	**165.3**	**1.0**	**91.9**	**1.0**	**112.6**	**1.0**	**310.7**	**1.0**
0-5 years	75.1	0.53	74.7	0.45	88.7	0.97	47.4	0.42	362.7	1.17
6 to 15years	151.5	1.07	128.7	0.78	85.8	0.93	108.7	0.97	410.1	1.32
16-70 years	155.9	1.10	200.1	1.21	95.5	1.04	130.7	1.16	266.6	0.86

2.4 Estimation of mean age specific consumption data

Mean age specific intake rate consumption data will be used to calculate doses for the population living beyond the Exclusion Area Boundary (EAB) i.e. within 80km. In order to estimate the mean age specific consumption rate for the Kenyan population, mean intake data for the total Kenyan population is provided in Tables 1,2 and 3. Correction factors for different age groups for calculation of the age specific intake rates are provided in Table 4. These values are then used to calculate age specific consumption rate (kg/year) as shown in Equation 2 and the results presented in Tables 5,6 and 7.

$$\text{Mean Age Specific Consumption (kg/year)} = \text{Mean Intake x Age specific correction factor} \quad (2)$$

Table 5: Mean Intake Rate of Plant (kg/year)

	Cereal	Maize	Veg	Fruits	Rice
Age Set 1 (6 Age Groups)					
Mean Intake	**135**	**69.5**	**41.8**	**70.5**	**20.6**
0-1 years	22.52	11.59	10.36	38.97	3.44
1 to <2 years	69.32	35.69	19.17	81.33	10.58
2 to <7 years	99.19	51.06	23.48	79.73	15.14
7 to <12 years	140.63	72.40	30.39	73.19	21.46
12 to <17years	147.79	76.08	34.47	56.65	22.55
more than 17y	148.58	76.49	50.60	73.23	22.67
Age Set 2 (3 Age Groups)					
Mean Intake	**135**	**69.5**	**41.8**	**70.5**	**20.6**
0-5 years	71.54	36.83	18.89	68.05	10.92
6 to 15years	144.40	74.34	32.54	65.85	22.03
16-70 years	148.58	76.49	50.60	73.23	22.67

Table 6: Mean Intake Rate of animals (kg/year)

	Bovine	Sheep & Goat	Poultry	Pig	Milk
Age Set 1 (6 Age Groups)					
Mean Intake	**14**	**1.1**	**2.6**	**0.4**	**93.3**
0-1 years	1.39	0.11	0.26	0.04	27.30
1 to <2 years	5.59	0.44	1.04	0.16	167.00
2 to <7 years	8.47	0.67	1.57	0.24	134.19
7 to <12 years	11.82	0.93	2.20	0.34	131.31
12 to <17 years	15.04	1.18	2.79	0.43	115.82
More than 17 y	16.25	1.28	3.02	0.46	80.06
Age Set 2 (3 Age Groups)					
Mean Intake	**14**	**1.1**	**2.6**	**0.4**	**93.3**
0-5 years	5.89	0.46	1.09	0.17	108.91
6 to 15 years	13.52	1.06	2.51	0.39	123.15
16-70 years	16.25	1.28	3.02	0.46	80.06

Table 7:Mean Intake Rate of Aquatic Food (kg/year)

	Fresh water fish	Marine water fish	Pelagic water fish
Age Set 1 (6 Age Groups)			
Mean Intake	**3.1**	**0.5**	**0.4**
0-1 years	0.31	0.05	0.04
1 to <2 years	1.24	0.20	0.16
2 to <7 years	1.87	0.30	0.24
7 to <12 years	2.62	0.42	0.34
12 to <17 years	3.33	0.54	0.43
more than17 years	3.60	0.58	0.46
Age Set 2 (3 Age Groups)			
Mean Intake	**3.1**	**0.5**	**0.4**
0-5 years	1.30	0.21	0.17
6 to 15 years	2.99	0.48	0.39
16-70 years	3.60	0.58	0.46

2.5 Estimation of maximum age-specific consumption

Maximum age specific consumption will be used to calculate the individual dose of a hypothetical person living on EAB and will be used to check if the reactor meets the specified criteria. According to Table 3.2 of ICRP 101 [2], maximum age specific values could be obtained based on average values for the more highly exposed group on a site-specific data or 95th percentile of appropriate national or regional data in the absence of site-specific data. However, there is no information on the site-specific data or 95th percentiles of national data except mean values.

Thus, in this study, maximum age specific values will be obtained by adjusting the mean age specific consumption based on multiplication by a proper value of 3 as shown in Equation (3). This multiplication value is chosen based on the paragraph 67 of ICRP 101 [2] that the 95th percentile of consumption rates for many staple foods tend to exceed the mean value of the distribution by approximately a factor of 3. This multiplication factor may be changed later through a further study. The results obtained for maximum intake rate of plant, animal and aquatic foods are presented in Tables 8,9 and 10 respectively.

$$\text{Maximum age specific intake} \\ = 3.0 \times \text{Age-specific mean intake} \quad (3)$$

Table 8: Maximum Intake Rate of Plant (kg/year)

	Cereal	Maize	Veg	Fruits	Rice
Age Set 1 (6 Age Groups)					
0-1 years	202.5	34.78	31.07	116.90	10.31
1 to <2 years	67.55	107.06	57.51	244.00	31.73
2 to <7 years	207.95	153.19	70.45	239.20	45.41
7 to <12 years	297.56	217.19	91.18	219.56	64.38
12 to <17 years	421.88	228.25	103.41	169.94	67.65
more than17 years	443.36	229.48	151.79	219.68	68.02
Age Set 2 (3 Age Groups)					
0-5 years	214.63	110.49	56.68	204.16	32.75
6 to 15years	433.19	223.01	97.62	197.56	66.10
16-70 years	445.75	229.48	151.79	219.68	68.02

Table 9: Maximum Intake Rate of animals (kg/year)

	Bovine	Sheep & Goat	Poultry	Pig	Milk
Age Set 1 (6 Age Groups)					
0-1 years	4.18	0.33	0.78	0.12	81.91
1 to <2 years	16.76	1.32	3.11	0.48	501.00
2 to <7 years	25.40	2.00	4.72	0.73	402.57
7 to <12 years	35.47	2.79	6.59	1.01	393.93
12 to <17 years	45.13	3.55	8.38	1.29	347.46
More than 17 y	48.76	3.83	9.05	1.39	240.19
Age Set 2 (3 Age Groups)					
0-5 years	17.68	1.39	3.28	0.51	326.74
6 to 15 years	40.56	3.19	7.53	1.16	369.45
16-70 years	48.76	3.83	9.05	1.39	240.19

Table 10: Maximum Intake of Aquatic Food (kg/year)

	Fresh water fish	Marine water fish	Pelagic fish
Age Set 1 (6 Age Groups)			
0-1 years	0.93	0.15	0.12
1 to <2 years	3.71	0.60	0.48
2 to <7 years	5.62	0.91	0.73
7 to <12 years	7.85	1.27	1.01
12 to <17 years	9.99	1.61	1.29
more than17 years	10.80	1.74	1.39
Age Set 2 (3 Age Groups)			
0-5 years	3.91	0.63	0.51
6 to 15 years	8.98	1.45	1.16
16-70 years	10.80	1.74	1.39

2.6 Comparison of US criteria with other countries

The Canadian CSA N288 1-14 (R2019) uses derived release limits to estimate the radioactive material in airborne and liquid effluent release from the normal operation of a nuclear facility. Additionally, for the protection of the public, they use a single public dose limit of 1mSv/year. Many assumptions which make the US NRCs regulatory guides adaptable are not considered here in the CSA document.

England's *Principles for the Assessment of Prospective Public Doses Arising from Authorized Discharges of Radioactive Waste of the Environment* are easier to be applied for new comer countries like Kenya in comparison to the Canadian and US criteria. This is because, two criteria would be enough to assess the doses to members of the public from a nuclear research reactor. The dose criteria used for assessment would include site constraint of 0.5mSv/year (for multiple reactors) and an effective source constraint value of 0.3mSv/year (for a single reactor).

However, for this study the 10 CFR Part 50, Appendix I & 40 CFR 190 will be used to calculate the doses from routine releases to the critical group. It is important to note that the US regulatory model criteria are very comprehensive, detailed and conservative. The

US dose criteria, which are being applied mutatis mutandis to a part of national criteria of Republic of Korea, consider seven annual dose limits for a single reactor as shown in Table 11.

Table 11: Annual Dose Limit Values for Liquid and Gaseous Effluent Release

Effluents	Category	Annual Dose Limit
Gaseous	Beta Air Dose	0.2mGy
	Gamma Air Dose	0.1mGy
	External Total Body Dose	0.05mSv
	External Skin Dose	0.15mSv
	Organ Dose	0.15mSv
Liquid	Total Body Dose	0.03mSv
	Maximum Organ Dose	0.01mSv

3. Conclusions

The INDAC code from Korea Institute of Nuclear Safety (KINS) will be used to estimate dose to individuals from reactor effluents. This will form the basis for comparing the values to the guidelines for releases in 10 CFR 50, Appendix 1. This research is still ongoing and the values obtained will be important in justifying the need for a research reactor and satisfying the Kenyan infrastructure issues.

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