Societal Statistical Data for a Food Chain Modeling of the UAE

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1. Introduction

The United Arab Emirates (UAE) is developing at a rapid rate and their increasing demand for energy led their decision on building a nuclear power plant. Nuclear energy was seen as a potential alternative for the current non-renewable energy sources such as oil, gas and coal. Nuclear power was then chosen due to its sustainable qualities as well as sufficiency in the supply of energy for the upcoming years [1]. In addition, it is believed that it will greatly contribute to UAE's economy and energy security [1]. Despite its promising qualities, the risk underlying nuclear fallout can be catastrophic. Therefore, for safety analysis, a prospective assessment on the potential risks associated with the occurrence of such event should be performed. Constructing a food chain model and an exposure pathway that is specific to the UAE is essential, as it could aid in the determination of the potential dose an individual could receive following a routine or accidental release of radionuclides into the environment. This paper includes societal statistical data such as data on the production of food as well as dietary data such as the consumption of food in the UAE. Such data was compiled along with other parameter values from the literature. These findings could potentially be used as input values upon the development of a food chain model.

2. Radionuclide Transport in a Terrestrial Environment

Airborne contaminants such as radionuclides that are suspended in the atmosphere ultimately deposit onto the earth's surface i.e. on the soil and/or vegetation under the influence of various mechanisms including gravitational settling, downward molecular diffusion, surface impaction, rainfall deposition, and electrostatic deposition [2]. Airborne particles could settle under the influence of gravity, with larger particles settling more rapidly than smaller ones. The rate of deposition can be enhanced due to the effect of downward molecular diffusion. This is a random process whereby due to natural air currents and eddies, airborne particles move downwards due to the gravitational pull but to a much greater extent than gravitational settling alone [2, 3]. Surface impaction is a mechanism whereby a particle collides with an object (i.e. surface) in its path. Some particles deposit permanently onto the surface, while others have the potential to bounce off the surface. Bouncing could lead to the reentrance of the particle to the air stream, or the deposition of the particle on a nearby surface [2]. When precipitation episodes such as rainfall dominate, particles fall as rainfall deposition. A condensation reaction takes place between the raindrop and the aerosol particle, and the combination of both masses leads to rapid settling of the particle. Similarly, electrostatic deposition also condenses aerosols, but it is based on electrovalent particle attraction. Particles of opposite charge attract, leading to a coagulation effect between these entities, increasing their mass which causes them to deposit at a faster rate [2, 3]. On land, contaminates present on the soil surface can be transported to the vegetation through root uptake and resuspension. Root uptake is restricted to contaminants which are present within the rooting zone and are therefore bioavailable. Settled particles could also be resuspended from the surface via wind or raindrop splash which may cause them to settle on neighboring vegetation [4]. Contaminants could also travel from the vegetation to the soil surface through weathering and senescence [5]. Potentially contaminated aerial particles could deposit onto the surface of plant foliage. In the process of weathering, the contaminants can be mechanically lost from the surface. While in the process of senescence, the plant may die and detach from the host plant, causing the contaminants that were associated with the plant foliage to reside on the soil surface. Once the contaminant is settled on the soil surface, it could further migrate within the soil column through leaching or percolation [5]. Leaching involves the migration of dissolved materials downward through the column as a result of water infiltration. Percolation on the other hand, involves the downward migration of particles and contaminants attached to them. All the pathways defined in this section are included in a dynamic model depicted in Fig. 1.

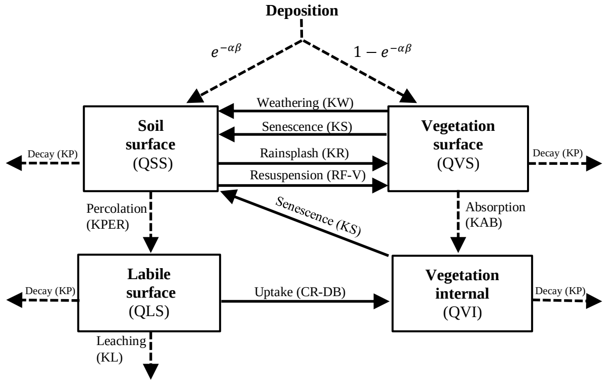

Fig. 1. A conceptual diagram that summarizes the possible pathways a contaminant can take in a terrestrial system [5]

Furthermore, animals residing at the top of the food chain could be exposed to contaminants mainly through inhalation and ingestion. Animals can be exposed to the contaminants by inhaling contaminated air or by consuming vegetation wherein polluted aerial deposits reside. These exposure pathways also apply to humans. Another pathway for human exposure is through animal derived food products. If a farming animal ingested or inhaled radionuclides, the food products such as meat, eggs, milk and other dairy products will also be contaminated.

Table I: Parameter values for the diagram in Figure 1 [5]

Parameter	Units	Description
α	$m^2\ kg^{-1}$	Foliar interception constant
B	dry kg m^{-2}	Plant biomass
DB	dry kg $m^{-2}\ d^{-1}$	Time derivative of plant biomass
KW	d^{-1}	Weathering rate constant
KS	d^{-1}	Senescence rate constant
RF	m^{-1}	Resuspention factor
V	m d^{-1}	Deposition velocity
KR	d^{-1}	Rainsplash rate constant
KPER	d^{-1}	Percolation rate constant
KP	d^{-1}	Physical decay constant
KAB	d^{-1}	Absorption rate constant
CR	-	Plant/soil concentration ratio
KL	d^{-1}	Leaching rate constant

Deterministic models that are used for describing the food chain transfer of radionuclides are divided into two categories namely equilibrium and dynamic models.

2.1 Equilibrium Model

Nuclear power plants are permitted to release reactor effluents during normal operation of the plant as long as the amount discharged is in compliance with standards set by regulators [6]. In order to assess the impact of the routine releases of radionuclides into the environment, an equilibrium model could be utilized [7]. The model contains well defined transfer parameters as well as a comprehensive database for all the environmental conditions. Also, the parameter values are often chosen in order to provide a conservative estimate of dose [7]. Furthermore, in order to calculate the annual dose to man from routine releases of reactor effluent, the following equation obtained from RG-1.109 could be utilized [8]:

Dose from atmospherically-released nuclides in food

$$\mathrm{D}_{\mathrm{ja}}^{\mathrm{D}}(\mathrm{r},\theta) = \sum_i DFI_{ija}\,[U_a^V f_g C_i^v(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_l C_i^L(r,\theta)] \quad (1)$$

where

$\mathbf{D}_{\mathbf{ja}}^{\mathbf{D}}(\mathbf{r},\boldsymbol{\theta})$: Dose to organ j of age class a from ingestion of all gaseous pathways mrem/yr,

$\boldsymbol{DFI_{ija}}$: Ingestion dose conversion factor for nuclide i to organ j in age class a mrem/yr per pCi ingested,

$\boldsymbol{U_a^V f_g C_i^v(r,\theta)}$: Intake of nuclide i from ingestion of non-leafy vegetables, fruits & grain,

$\boldsymbol{U_a^m C_i^m(r,\theta)}$: Intake of nuclide i from ingestion of milk,

$\boldsymbol{U_a^F C_i^F(r,\theta)}$: Intake of nuclide i from ingestion of meat,

$\boldsymbol{U_a^L f_l C_i^L(r,\theta)}$: Intake of nuclide i from ingestion of leafy vegetables.

2.2 Dynamic Model

Accidental release of radionuclides is a possibility in a nuclear power plant. Dynamic models are capable of not only assessing accidental releases but also operational ones. They are time-dependent models, whereby they can be applied to discharges that vary as a function of time. In addition, they account for linkages between the comportments of the system as well as changing rates [7]. However, a large parameter database is not always available and parameters are often difficult to derive. Major assumptions are made for values such as soil bulk density. An example of a dynamic model called PATHWAY is displayed in figure. 1. This system could be described through the following differential equations:

Soil surface [5]:

$$\frac{d\mathrm{QSS}}{dt} = \mathrm{Dep}\cdot e^{-\alpha B} + (\mathrm{KW}\cdot\mathrm{QVS}) + [\mathrm{KS}\cdot(\mathrm{QVS}+\mathrm{QVI})] - [(\mathrm{RF}\cdot\mathrm{V}) + \mathrm{KR} + \mathrm{KP} + \mathrm{KPER}]\cdot\mathrm{QSS} \quad (2)$$

Vegetation surface [5]:

$$\frac{d\mathrm{QVS}}{dt} = \mathrm{Dep}\cdot(1-\mathrm{e}^{-\alpha B}) + [(\mathrm{RF}\cdot\mathrm{V}+\mathrm{KR})\cdot\mathrm{QSS}] - [(\mathrm{KW} + \mathrm{KP} + \mathrm{KAB} + \mathrm{KS})\cdot\mathrm{QVS}] \quad (3)$$

Vegetation internal [5]:

$$\frac{d\mathrm{QVI}}{dt} = \mathrm{KA}B\cdot\mathrm{QVS} + \left[\mathrm{CR}\cdot\mathrm{D}B\cdot\frac{\mathrm{QLS}}{(\mathrm{XR\cdot PS})}\right] - [(\mathrm{KP}+\mathrm{KS})\cdot\mathrm{QVI}] \quad (4)$$

Labile soil [5]:

$$\frac{d\mathrm{QLS}}{dt} = \mathrm{KPER}\cdot\mathrm{QSS} - \left[\mathrm{CR}\cdot\mathrm{D}B\cdot\frac{\mathrm{QLS}}{(\mathrm{XR\cdot PS})}\right] - [(\mathrm{KP}+\mathrm{KL})\cdot\mathrm{QLS}] \quad (5)$$

3. U.A.E Statistical Findings

Radionuclides, either released routinely or accidentally from a nuclear power plant can travel and bioaccumulate along successive trophic levels of a food chain ultimately exposing individuals to internal radiations. One of the major pathways by which a radionuclide enters the body is through ingestion. Hence, in order construct a food chain model and thereby predict the dose of ingested radionuclides, compiled statistical data on UAE food production, domestic consumption and per capita consumption can be utilized. Significant amount of food is imported to the UAE. The portion that is locally produced is displayed in Table IV. The animal species that are consumed in the UAE include goats, camels, poultry, cattle and sheep. Locally produced meat from these animals is generally consumed by locals who represent approximately 15% of the UAE population, as the animals are slaughtered following Islamic requirements set by the UAE government [9]. Furthermore, dairy products such as milk could be produced from indigenous mammals including cattle, goats, sheep and cows. Foodstuff including legumes (e.g. soybean meal and soybean oil), fruiting vegetables (e.g. dates and tomatoes), and root vegetables (e.g. onions) are also produced in the UAE. However, grains including barley, milled rice and wheat are all imported from abroad and not locally produced. Gathering information on local produce can be used as a starting point to determine potential radionuclide exposure pathways that eventually impact the public. As addressed in the section above, animals could intentionally or involuntary ingest radionuclides through contacting the contaminated soil surface or via consuming polluted vegetation. To determine the amount of radionuclides transported from vegetation to an animal, the rate of ingestion can be obtained through using the below equation [5]:

$$R_{ing} = a \sum_i r_i C_{veg_i} \qquad (6)$$

where
a = fraction of an ingested quantity that is transferred a particular organ or tissue,
r_i = rate of ingestion of species or item i (kg/d), and
C_{veg_i} = average concentration of the radionuclide in species or item i (bq/kg).

Experimenters were able to obtain feeding and assimilation rates of animals through conducting experiments such as measuring such parameters with the presence of radiotracers such as Cesium (^{137}Cs) [10]. Ingestion rates of animals could be obtained from the literature, as presented in Table II [11]. In addition, it should be noted that due to the absence of site- and scenario-specific data in the UAE on parameters shown in Table I, such values could be obtained from the International Atomic Energy Agency (IAEA) as generic input values [12].

Table II: Compiled data on animal ingestion rates [11]

	Unit of Measurement: kg(dry weight)/day				
Animal	Average Consumption Value			Plant Ingestion Rate	Soil Intake Range
	Grain	Forage	Silage		
Beef Cattle	0.47	8.8	2.5	12	-
Dairy Cattle	2.6	11	3.3	17 [13] 0.4 [14]	0.17-3.1 [13] 0.1-0.7 [14]
Chicken	0.08	-	-	-	-
Sheep	-	1.4	-	1.4	0.28-0.42

Furthermore, per capita and domestic consumption of food in the UAE have been tabulated in Tables III and V respectively. A major exposure pathway is the animal derived food products. As shown in Table III, individual's meat diet is mostly comprised of poultry. This implies that humans will be greatly impacted if the poultry was exposed to radionuclides through a variety of exposure pathways.

Table III: Per capita consumption of foodstuff in the UAE

	Unit of measurement: kg/person/year				
Year	2007	2008	2009	2010	2011
Potato [15]	-	21.5	9.60	8.40	10.9
Tomato [15]	-	28	14.8	21	22.1
Onion [15]	-	23.9	16	16.4	14.9
Date [15]	-	8.09	7.13	7.11	6.72
Sheep & Goat [15]	-	13.8	9.81	8.34	7.55
Poultry	49.2 [16]	44.4 [15]	43.8 [15]	37.5 [15]	39.4 [15] 44 [17]
Cheese [15]	-	4.27	3.92	4.91	3.01
Egg [15]	-	8.51	7.61	5.86	5.33
Milk [15]	-	-	90.6	83.3	75.1

Table IV: Local production of foodstuff in the UAE [19]

	Unit of measurement: MT					
Year	2007	2008	2009	2010	2011	2012
Dates	757,600	757,600	759,000	825,300	239,164	250,000 (F)
Meat indigenous, camel	21,205 (Fc)	21,960 (Fc)	23,562 (Fc)	32,792 (Fc)	40,458 (Fc)	27,296 (Fc)
Meat indigenous, chicken	24,461 (Fc)	33,434 (Fc)	37,753 (Fc)	39,635 (Fc)	27,296 (Fc)	41,058 (Fc)
Meat indigenous, goat	10,596 (Fc)	10,994 (Fc)	12,135 (Fc)	19,280 (Fc)	16,155 (Fc)	16,955 (Fc)
Meat indigenous, cattle	3,068 (Fc)	8,121 (Fc)	3,840 (Fc)	7,309 (Fc)	13,518 (Fc)	13,893 (Fc)
Meat indigenous, sheep	6,378 (Fc)	6,729 (Fc)	7,857 (Fc)	5,176 (Fc)	5,418 (Fc)	5,508 (Fc)
Eggs, hen, in shell	25,350	25,350	30,000 (F)	28,000 (F)	28,500 (F)	29,000 (F)
Milk, whole fresh goat	37,930	39850 (F)	44,200 (F)	43,200 (F)	47,250 (F)	48,500 (F)
Milk, whole fresh camel	41,109 (Im)	41,436 (Im)	40,356 (Im)	42,400 (Im)	43,000 (Im)	45,000 (F)
Milk, whole fresh cow	18,038	20,000 (F)	35,000 (F)	36,500	38,300	39,500
Milk, whole fresh sheep	16,046	13,650 (F)	15,800 (F)	17,500 (F)	18,000 (F)	19,000 (F)
Tomato	58,965	127,405	68,298	47,411	58,668	60,000
Mangoes, mangosteens, guavas	10,970	16,753	11,000	10,600	5,681	8,000 (F)
Vegetables, fresh nes	30,189	19,977	32,440	28,400	26,368	27,000 (F)
Pumpkins, squash and gourds	18,565	29,019	19,934	27,419	23,117	23,000 (F)
Eggplants (aubergines)	11,512	12,935	18,583	19,064	11,377	11,500 (F)
Fruit, fresh nes	6,453	11,242	12,500 (F)	10,615	13,381	14,000 (F)
Onions, shallots, green	12,957 (Im)	13,408 (Im)	15,068 (Im)	14,104 (Im)	15,196 (Im)	16,000 (F)
Almonds, with shell	850 (F)	-	1,099 (Im)	909 (Im)	1,168 (Im)	1,200 (F)
Lemons and limes	-	-	-	5,482	-	-
Carrot and turnips	-	-	8,600 (F)	-	9,470 (Im)	9,500 (F)
	Unit of measurement: 1000 MT					
Year	2011	2012	2013	2014	2015	2016
Soybean meal [18]	110	157	106	45	39	39
Soybean oil [18]	26	37	25	11	9	9

F: FAO estimate
Fc: Calculated data
Im: FAO data based on imputation methodology

Table V: Domestic consumption of foodstuff in the UAE

	Unit of measurement: 1000MT						
	2010	2011	2012	2013	2014	2015	2016
Soybean meal [18]	285	377	462	247	187	202	212
Soybean oil [18]	60	60	50	45	35	32	35
Barley [18]	334	524	541	468	367	500	400
Milled rice [18]	480	520	540	560	580	600	610
Wheat [18]	850	1,000	1,200	1,225	1,250	1,300	1,350
Beef & Veal meat [18]	43	55	66	62	61	78	76
Poultry [18]	226	242	245	242	229	307	366

	Unit of measurement: kt			
	2008	2009	2010	2011
Egg [15]	57.9	58.7	49.5	47.5
Sheep & goat meat [15]	93.5	75.7	70.4	67.3
Tomato[15]	190	114	178	197
Onion [15]	162	123	139	133
Date [15]*	55	55	60	59.9
Cheese [15]	29	30.3	41.4	26.8
Milk [15]	-	699	703	669

*Faostat, National Statistical Office, Helgi Analytics calculation.

4. Conclusion

The Barakah nuclear power plant will soon start operating in the UAE, and it is therefore critical that safety assessments in case of nuclear fallout be made. Following fallout, radionuclides can travel along successive trophic levels of a food chain, ultimately affecting humans. Yet, the exposure pathway by which it is transported varies between countries depending on the plant and animal species considered as well as other climatic factors. Hence, developing a food chain model specific to the UAE environment is essential, as it will aid in the determination of the potential dose an exposed individual might receive. Available societal data specific to the UAE from the year 2007 to 2016 were compiled. The data is comprised of UAE food production, domestic and per capita consumption. In addition, supporting data from the literature were acquired and presented in this paper. Such data can be used as input values upon developing the food chain model specific to the UAE.

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