Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Assessment of Transportation Risk of Radioactive Materials in Uganda

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1. Introduction

Transportation of radioactive materials is directly associated with the progress in every activity involving the use of nuclear energy, including research, education, medicine, industry, nuclear fuel cycle and power generation. Increasing numbers and quantities of radioactive materials in many different forms are being transported throughout the world, which result in an increased public concern about radiation safety in transport. Radioactive materials refer to any materials that spontaneously emit ionizing radiation and of which the radioactivity per gram is greater than 0.002 micro-curie [1].They include: spent nuclear fuel, nuclear wastes, medical sources i.e. Co-60, industrial sources i.e. Cs-137, Am-241:Be, Ra-226, and sources for research.

In view of the rising reported cancer cases in Uganda [2], which might be as a result of radiation exposure due to constant transportation of radioactive materials i.e. industrial sources, a risk analysis was thought of and undertaken for the country's safety evaluation and improvement. It was therefore important to undertake a risk assessment of the actual and potential radiation exposure during the transportation process.

This paper explains a study undertaken for transport risk assessment of the impact on the environment and the people living in it, from exposure to radioactivity during transportation of the industrial sources in Uganda. It provides estimates of radiological risks associated with visualized transport scenarios for the highway transport mode. This is done by calculating the human health impact and radiological risk from transportation of the sources along Busia transport route to Hoima. Busia is the entry port for the sources whilst Hoima, where various industrial practices that utilize sources like oil explorations are centered.

During the study, a computer code RADTRAN-6 was used.

2. Methodology

The software modeling tool RADTRAN-6 was applied for determining the radiological doses that would be received by workers (e.g. drivers, handlers) and by members of the general public. The original RADTRAN code was developed by Sandia National Laboratories (SNL) in 1977. The radiation exposures received by the workers and public, determines the associated risk involved along the transportation route.

Risk in this case is referred to as the product of the probability of an occurrence of an undesirable event and the consequence of the desirable event i.e. [Risk = (probability) x (consequence)].

2.1 Conceptual model

Factors associated with the transportation of radioactive materials are categorized as either radiological or non-radiological impacts. The accident release of radioactive material into the environment for instance, is a factor related to radiological impacts; this includes the effects from ionizing radiation as a result of incident-free transportation and thus leading to incident-free consequences.

Accidents resulting in death when there is no radioactive material released to the environment are associated with non-radiological impacts.

Figure 1 shows RADTRAN flow diagram in which from the package models, one obtains the incident-free consequences. This holds for cases with transport infrastructure and population distribution. Alternatively, given the transport infrastructure and population distribution, one obtains the non-radiological fatalities depending on the severity of the accident.

In case of radiological impacts, there is a probability of the particulate material released into the environment, this depends on the severity of the accidents, exposure pathways and therefore dose risk arising from accident scenarios and consequently the health effect risk in a form of latent cancer fatality.

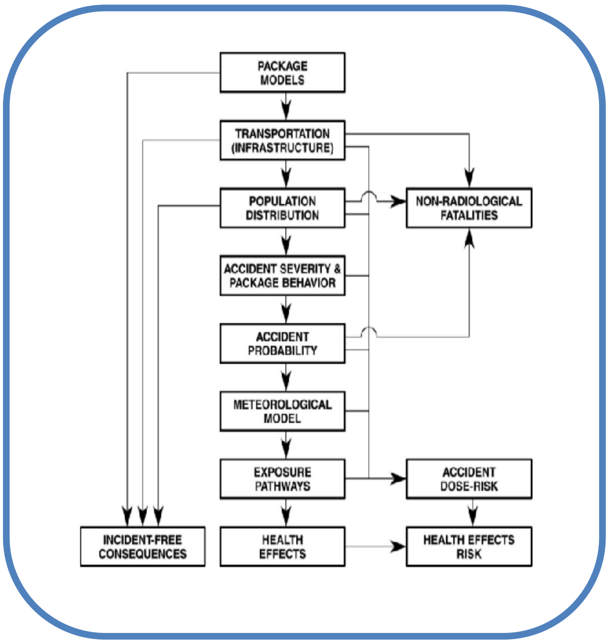

Fig. 1: Flow diagram

2.2 Mathematical Model

There are various equations used to calculate dose to people exposed during incident-free and accident transportation. There are many equations used for different scenarios such as computing the dose to the population along the route and computing Off-Link Dose. These are discussed in more details in Radcat User Guide [3].

3. Input data

A large amount of input data was used. Some of the data was obtained from the actual conditions and others were taken from the default values given in the code. Detailed discussion is given below for each of the parameters used.

3.1 Transport situation data (Normal data)

The transport situation used is transport of a truck travelling from Busia to Hoima. In this case, the transportation mode used is highway as shown in Fig. 2 and Fig. 3 shows the route undertaken. Some of data used is presented in Table 1.

Fig. 2: Uganda highway road

Fig. 3: Undertaken highway route (see bolded black line)

Table 1: Some of incident-free input data

Variable	Value	Comments
Vehicle size	12	Length of the trailer excluding the horse
Crew	2	Mainly drivers
Number of stops/time 1st stop Jinja 2ndstop Mukono	2 30 minutes 1 hour	These stops are mainly for refueling and refreshments
Average Vehicle speed Urban: Suburban: Rural:	40km/hr 50 km/hr 65 km/hr	These speeds vary from place to place depending on the speed limits

3.2 Accident data

The impact on the package that could lead to the release of particulate matter into the atmosphere is considered, information on accident statistics is included in Table 2.

If the accident were to occur, depending on the severity of the accident, the package could be breached and thereby releasing particulate matter into the atmosphere. A fraction of the material released is referred to as the release fraction, which is a function of the accident severity. The report of [4] shows that the most fatal crashes, in 2007 for trucks on the Ugandan roads were 2838 per 363658 registered road accidents. This is the conservative value used in the calculations. Particle size is important in determining the total release fraction, only fractions that are inhaled are considered in the calculation of inhalation dose.

Considering the radionuclides transported conforms to IAEA regulations, it is expected that only a small fraction is dispersed, this is especially true if the inventory contains very little of nuclides such as Radium-226. A conservative approach was to employ a release fraction of only 0.8 for the package under severe impact conditions. This value is very small for the type B packages; in principle it is a value between 0 and 1, which depends on the package strength. 0 means there are no particulate matter released while 1 means the package is completely destroyed and thereby disabling it from material containment.

Table 2: Some of Accident input data

Variable	Value	Comments
Release fraction	0.8	If the release fraction is 1, then the package is totally destroyed, and 0 implies the package is unbreached
Deposition Velocity	0.01 m/sec	Velocity of particulate matter in the atmosphere
Accident probability fraction	2.45×10^{-4}	Uganda's number of trucks involved in fatal crashes per registered vehicles (2007 statistics)
Crew Shielding Factor	0.5	This factor is the fraction of ionizing radiation to which the crew is exposed, it is between 0 and 1, where 1 implies no shielding and 0 is 100% shielding

3.3 Material data

RADTRAN-6 has an internal library of isotopes which contains data for more than 50 of the most commonly transported radioisotopes. The user, however, can use the DEFINE option to change the material data in the data library. The BLOCK DEFINE can be used also to introduce a new radioisotope not included in the radionuclides library.

3.4 Population density data

According to the given classifications in the computer code, all the districts are considered as Suburban Zones. The default value of shielding factor which describes the shielding effect of buildings in Rural, Suburban and Urban zones was taken from the RADTRAN-6 code. This is shown in the Table 3.

Table 3: Population density data for each district

Districts	Population densities/km^2	Type of Area
Busia	407.2	Suburban
Bugiri	408.1	Suburban
Iganga	490.3	Suburban
Mayuge	426.1	Suburban
Jinja	744.9	Suburban
Buikwe	345.1	Suburban
Mukono	293.9	Suburban
Wakiso	719.4	Suburban
Mityana	197.3	Suburban
Kiboga	104.0	Suburban
Kyankwanzi	74.5	Suburban
Hoima	149.8	Suburban

[Source: Uganda national census 2011 Estimate and 2012 Estimate]

3.5 Radionuclide input data

Table 4 shows radioactive materials considered. Independent measurements of each shipping container at one meter were carried out. A radiation survey meter type: IdentiFINDER and radiation Model, AT1117M was used for taking the measurements.

Table 4: Radionuclide materials specifications

Radioactive material	Maximum Activity (Ci)	Maximum Activity (Bq)	Dose rate (µSv/hr)	Dose rate (mrem/hr)	Gamma fraction	Neutron fraction
Cs-137	2.5	9.25E10	3.20	0.32	1.0	0.0
Ra-226	2.5E-3	9.25E07	1.50	0.15	1.0	0.0
Am-241: Be	15	5.55E11	5.12	0.51	0.85	0.15

[Source: Atomic Energy Council Inspection report, 2012]

4. Results

The results of the computer code RADTRAN-6 are given for incident-free condition in the form of annual collective dose received by a number of population subgroups, and for accident conditions in the form of population dose and health effects.

4.1 Normal conditions

Table 5 shows the incident-free doses resulting from RADTRAN-6 calculations through various districts summarizing the collective exposure dose in person-sievert for each district in different population subgroups. The resulting doses are insignificant as shown in Table 5 and can be associated with any non-radiological transportation. For the selected districts i.e. Busia, Bugiri and Iganga, it is shown that exposure dose rate is highest through Bugiri (i.e. 2.60E-5) for the population, and for Package transport crew, the exposure dose rate is highest through Iganga (i.e. 1.72E-5) implying more attention needed towards attainment of safety of the people. These exposure dose rates are high; however they are less than the exemption value of 1.0 mSv for public recommended by IAEA regulations and Uganda regulatory authority.

Table 5: Some of Incident-free RADTRAN results

Dose receptor	Exposure dose risk(person- sieverts)
Transport through Busia	
Population (Off-link)	1.21E-5
Package transport Crew	2.18E-5
Transport through Bugiri	
Population (Off-link)	1.45E-5
Package transport Crew	2.60E-5
Transport through Iganga	
Population (Off-link)	1.72E-5
Package transport Crew	2.57E-5

4.2 Accident conditions

Table 6 presents the RADTRAN-6 output for the expected values of population risk in person-sievert for Busia link, taking into account ground-shine, direct inhalation, inhalation of resuspended material and cloud-shine. The table presents the total estimated risks only, and shows that Am-241: Be has the highest risk value. The overall radiological risk is very low implying that no health effects are to be expected.

Table 6: Accident RADTRAN results

Radioactive Material	Direct Inhalation	Inhalation of resuspended material	Cloud-shine	Ground-shine	Total
Cs -137	1.29E-5	1.08E-7	3.14E-06	3.92E-05	5.54E-5
Ra- 226	7.78E-6	6.50E-8	6.06E-11	7.61E-10	7.85E-6
Am-241:Be	3.23E-5	2.20E-7	1.32E-07	4.52E-05	4.34E-5
Overall Total					6.32E-5

4.3 Compliance with the regulations

The values for the annual limits of exposure to the public and workers are 1.0 mSv and 50 mSv, respectively. These values are based on the recommendations given in IAEA (1985) and IAEA (1982), and are adopted for use in Uganda by Atomic Energy Council, the regulatory body.

5. Conclusions

The overall collective dose for population and package transport crew are 3.72E-4 and 1.69E-4 person-sievert respectively. These are less than the exemption value recommended by the IAEA and Uganda Regulatory Authority for public implying that no health effects like cancer are to be expected. Hence the rising cancer cases in the country are not as a result of increased transportation of radioactive materials in the Industrial sector. It is therefore concluded that the used highway radioactive materials transport route in

Uganda is safe and has acceptably low societal, individual and expected risk values.

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