Jurnal Sains Nuklear Malaysia, 2015, 27(2): 23-30
ISSN: 2232-0946

RADIOLOGICAL IMPACT ASSESSMENT IN DISPOSAL OF TREATED SLUDGE

Khairuddin Mohamad Kontol, Ismail Sulaiman and Faizal Azrin Abdul Razalim

Malaysian Nuclear Agency (NUCLEAR MALAYSIA),
Bangi, 43000 Kajang, Selangor Darul Ehsan, Malaysia
Correspondence author: khairuddin-m@nm.gov.my

ABSTRACT

Sludge and scales produced during oil and gas production contain enhanced naturally occurring radioactive material (NORM). Sludge and scales are under the jurisdiction of Department of Environment (DOE) and also Atomic Energy Licensing Board (AELB). AELB has issued a guideline regarding the disposal of sludge and scales as in its guideline (LEM/TEK/30 SEM.2, 1996). In this guideline, Radiological Impact Assessment (RIA) should be carried out on all proposed disposals and has to demonstrate that no member of public will be exposed to more than 1 mSv/y. This paper presented RIA analysis using RESRAD computer code for the disposal of treated sludge. RESRAD (RESidual RADioactive) developed by Argonne National Laboratory is to estimate radiation doses and risks from residual radioactive materials. The dose received by the member of public is found to be well below the stipulated limit.

Keywords: NORM, radiological impact assessment, RESRAD, treated sludge

INTRODUCTION

Oil and gas industry is a key component in Malaysia's economy. Oil and gas is a major contributor to the nation revenue. The industry is the largest recipient of foreign direct investment and one of the biggest sources of foreign exchange. This industry has transformed its rural landscape and brought about much socio-economic changes (e.g. Kertih in Terengganu and Bintulu in Sarawak) from sleepy fishing villages into world-class petroleum and liquefied natural gas (LNG) complexes exporting petroleum, petrochemicals products and LNG all over the world. Malaysia has a number of offshore platforms and onshore facilities for production and processing of oil and gas. The production and extraction of oil and gas produced wastes containing naturally occurring radioactive materials (NORM). The waste streams most likely to be contaminated with NORM including:

- Scales or hard deposits in production tubulars and topside equipment which has been in direct contact with the production stream,
- Contaminated sludge, sand, clay and heavy oil in the production system (separators, skimmer tanks etc.),
- produced water,
- condensates and contaminated steel in production, transport and storage systems in gas production (and/or in mixed oil-gas production),
- NORM residues in decommissioning of production installations and restoration of NORM contaminated areas

NORM is known to contain certain amount of radioactivity. The sources of the radioactivity are isotopes of ^{238}U and ^{232}Th series. The primary radionuclides of concern are ^{226}Ra and ^{228}Ra compared to other radionuclide due to their solubility and mobility in water. ^{226}Ra poses a long term hazard due to its long half-life (1600 years) and of concern in environmental protection. Problem of radium (Ra) arises from activities enhancing NORM waste such as uranium mining, oil and gas industries and mineral processing (Ibrahim et al., 2009). Ra in formation water (low sulphate) in reservoir rocks is brought up in crude oil. Then, Ra will precipitate as scales together with calcium (Ca), strontium (Sr) and barium (Ba) (usually as carbonate & sulphate compounds) when there is pressure and temperature drop. The concentration of uranium (U) and thorium (Th) in oil sludge and scale is normally low. The oil sludge and scales contained heavy metals and is categorised as scheduled waste and under the purview of Department of Environment (DOE). Besides that, due to the presence of elevated NORM in the waste, it is also under the purview of the Atomic Energy Licensing Board (AELB). AELB has issued a guideline *LEM/TEK/30 SEM.2 (1996)* regarding the management of waste from the oil and gas industry. Another document, code of practice LEM/TEK/58 has also been issued in 2009. Normally, the oil sludge and scales are temporarily stored in drums at the crude oil terminal premise. For disposal purpose, the waste will normally be treated and disposed of by dumping in a trench or big hole and cover with certain thickness of soil (BUL E2, 1992). The disposal site should be owned by the user (or waste producer) and approved for disposal by the relevant authority. Normally, the disposal site is located within the company's premise for easy control and monitoring.

Treated sludge is the sludge that has gone through process of removing (or separating) hydrocarbon from wastewater and solid sediment. The treatment processes includes:

- Biodegradation involving dilution of sludge and heavy metals with soils. It is not suitable for gas processing sludge containing mercury (Hg), which is volatile and very toxic. It requires a large area of land and the process is slow. Certain chemical can accelerate biodegradation. This method is the most practiced in oil and gas industry in Malaysia.
- Chemical extraction method using chemicals to separate hydrocarbon, waste water and solid sediment. Waste water containing oil and heavy metals need treatment prior to discharge. The final waste is the sediment which consists of sand or clay in a smaller volume.
- Incineration of hydrocarbon at high temperature (1200º C) producing fly and bottom ash. Ash is the final waste that needs to be disposed of or reused.
- Steam at 500º C to separate hydrocarbon from sediment

It is well known that NORM is hazardous to health and it has long been recognized that work with NORM can raise significant radiation exposure. Therefore, based on Malaysian regulations, Radiological Impact Assessment (RIA) should be carried out on all proposed disposals of NORM wastes and demonstrate that no member of the public will be exposed to more than annual permissible dose limit set by the AELB. RIA study on disposal of mineral waste has also been conducted (Azlina et al., 2003; Khairuddin et al., 2007). This paper described the RIA study on disposal of treated sludge conducted in Malaysia before the code of practice LEM/TEK/58 was issued.

The site of concern for disposal is located uphill and near the South China Sea with an area of 500 m x 40 m (20000 m^2). Most of the land located in immediate surrounding is still undeveloped and remained as empty land with fully–grown shrubs and small tress. The volume of treated sludge to be disposed off is 80000 m^3 with a depth of 4 m.

The study analysed and assessed the possible radiological impact to be incurred on identified critical groups of the population living on the proposed disposal site of the treated sludge. Analysis was made based on criteria and limits given in the existing regulations and guides pertaining to radiation protection issued by AELB, IAEA and some other relevant scientific reports elsewhere.

MATERIALS AND METHODS

Source Term and K_d

Treated sludge is the source of exposure. The amount of radioactive material in treated sludge is called the source term. The source term is the most important parameter to be used in the RIA study. In determining the source term, there were 30 treated sludge samples to be disposed were collected and also 20 surface soil samples (top 5 cm for background determination) were taken around the proposed disposal site. The samples were prepared, put into 350 ml plastic container, sealed and kept for at least three weeks to allow radionuclide radium attaining secular equilibrium with its progenies before analysing their radioactivity content using gamma spectrometry system (OXFORD HpGe + GammaTrac). In addition, another parameter, distribution coefficient (K_d) of radionuclide radium in sludge was also determined as described in the RESRAD handbook (Yu et al., 1993). K_d is an important parameter in determining the ability of radionuclide from the material migrating and entering groundwater system.

Radiological Criteria

The AELB has set certain radiological criteria that need to be fulfilled before disposal can be approved. The criteria's include the annual dose limit and dose constraint. The annual dose limit to the member of public is 1 mSv/y and collective dose of 1 man.Sv. Dose constraint of 0.3 mSv/y (about 1/3 dose limit for member of public) was also used in this assessment. If the calculated public dose is less than 0.3 mSv/y, the disposal is exempted from regulatory control. On the other hand, if the public dose is greater than 0.3 mSv/y (but still < 1 mSv/y), then the disposal is controlled under the regulation and environmental monitoring may be required to be conducted for a specific period determined by AELB.

Site Characteristics

The biosphere and geo-sphere are important routes for the transport of radioactive releases to the environment and thereby to man. These site characteristics parameters which include meteorology data (e.g. wind speed, wind direction, precipitation) were obtained from the Meteorological Department. The weather station for the measurements of the various meteorological parameters were taken was at the nearest airport. The procedures and standards adopted in collecting the data were in accordance with those recognised by the World Meteorological Organisation (WMO). Besides that, hydrology, geology, demography, human activities and future land use of the site and around the site were obtained from various references or relevant organisations. On the other hand, if the site specific information were not readily available, default or generic data will be used.

Critical Groups

The critical groups who will be affected by the disposal activity have been identified. They include the people who will live or work at the site and around the site after the disposal of waste for the whole assessment period.

Critical Pathways

Critical pathways for the estimation of dose to the critical groups by different migration patterns and modes of transport of radionuclide in passing through the environment have been identified. The critical pathways considered in the assessment would be external radiation, inhalation of dust (including radon and thoron daughters) and intake through food chain (leafy vegetables, drinking water, aquatic and meat).

Exposure Scenario

In order to assess the maximum impact or dose received by the critical groups, worst case scenario was selected. The scenario involves the use of the land for residential purposes. It was assumed that after NORM waste disposal, people (critical group) built houses and lives on the site. They were exposed to external radiation, inhaling airborne dust and radon and thoron progenies emitted by the waste. They were also relied on ground water onsite as a source of drinking water, cooking, irrigation and for livestock which will give internal exposure.

It was also assumed that the resident spent 21 hours each day onsite (17 hours spent indoors and 4 hours outdoor onsite) for 365 days per year. Another 3 hours assumed to be spent outside the disposal area. The house was assumed to be built with a soil cover of 0.05 m (the value chosen was from the assessment in order for the maximum dose obtained to be less than 0.3 mSv/y) and foundation thickness of 0.15 m. There is no erosion occurred by assuming the integrity of the soil cover and contaminated zone area (treated sludge) and the building foundation would be maintained. The exposure pathways evaluated included external radiation, inhalation of airborne particulate and radon (inhalation rate of 8400 m^3/y), ingestion of plant (44 kg/y), milk (92 L/y), meat (63 kg/y), aquatic foods (6.3 kg/y), soil and drinking water (510 L/y) assumed grown and taken on site. Two hundred peoples were assumed to live on site. Default data were used since there were no available site specific or generic data for Malaysia.

Modelling

Generally, in RIA, dosimetric models where mathematical models were developed based on the exposure pathways and identified scenarios to calculate the dose received by the critical groups. In this study, RESRAD computer code (RESRAD 6.1) developed by Argonne National Laboratory, USA was used. The code was designed to estimate radiation doses and risks from residual radioactive materials (in this case, residual radioactive materials are from NORM wastes). The code was accepted and widely used worldwide.

RESULTS AND DISCUSSION

The mean radioactivity of treated sludge and background soil samples are shown in Table 1. The radium concentrations in treated sludge and soils were in the range as reported in Malaysia (Omar et al., 1991; Omar et al., 2004; Sulaiman et al., 2014). The K_d of radium radionuclide in treated sludge was found to be 560 ml/g. Based on the selected scenario, the source term, K_d and other relevant parameters were then input into the RESRAD code. The results of the assessment are shown in Figure 1 and Figure 2.

Table 1: On site radioactivity of treated sludge and soil

	Concentration (Bq/kg)	
	^{226}Ra	^{228}Ra
Treated sludge	82 ± 49	97 ± 68
Soil	20 ± 8	34 ± 14

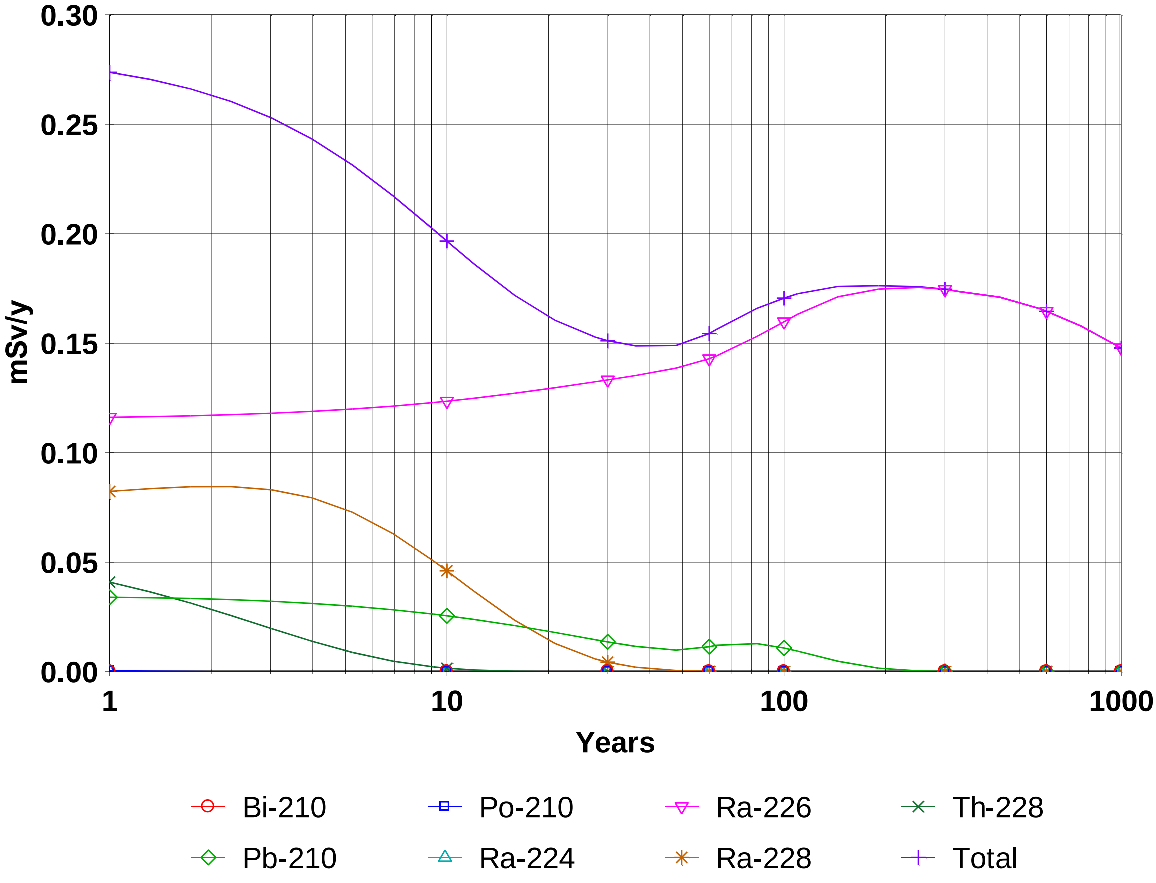

Figure 1: Annual effective dose from various radionuclides

The total maximum dose of 0.27 mSv/y occured during the first year exposure (Fig. 1). As radionuclides migrated into deeper soil and groundwater, it decreased to minimum (0.15 mSv/y) after 40-50 years. The total dose reached peaks (0.18 mSv/y) after 200-300 years period probably due to many radionuclides have entered into water dependent pathways.

The maximum dose received by the critical groups (0.27 mSv/y) is well below the limit set by the regulatory body of 1 mSv/y and dose constraint of 0.3 mSv/y. This implies that the proposed site can be used as a disposal site for treated sludge and is exempted from the regulatory control (i.e. no need for environmental monitoring). In term of collective dose to the public living on the site i.e. assuming 200 peoples (residential scenario), it was estimated that the annual collective doses received by the residential population were 0.05 man.Sv. Similar to the individual doses, this estimated dose also fall within the acceptable collective dose limit of the criteria namely 1 man.Sv.

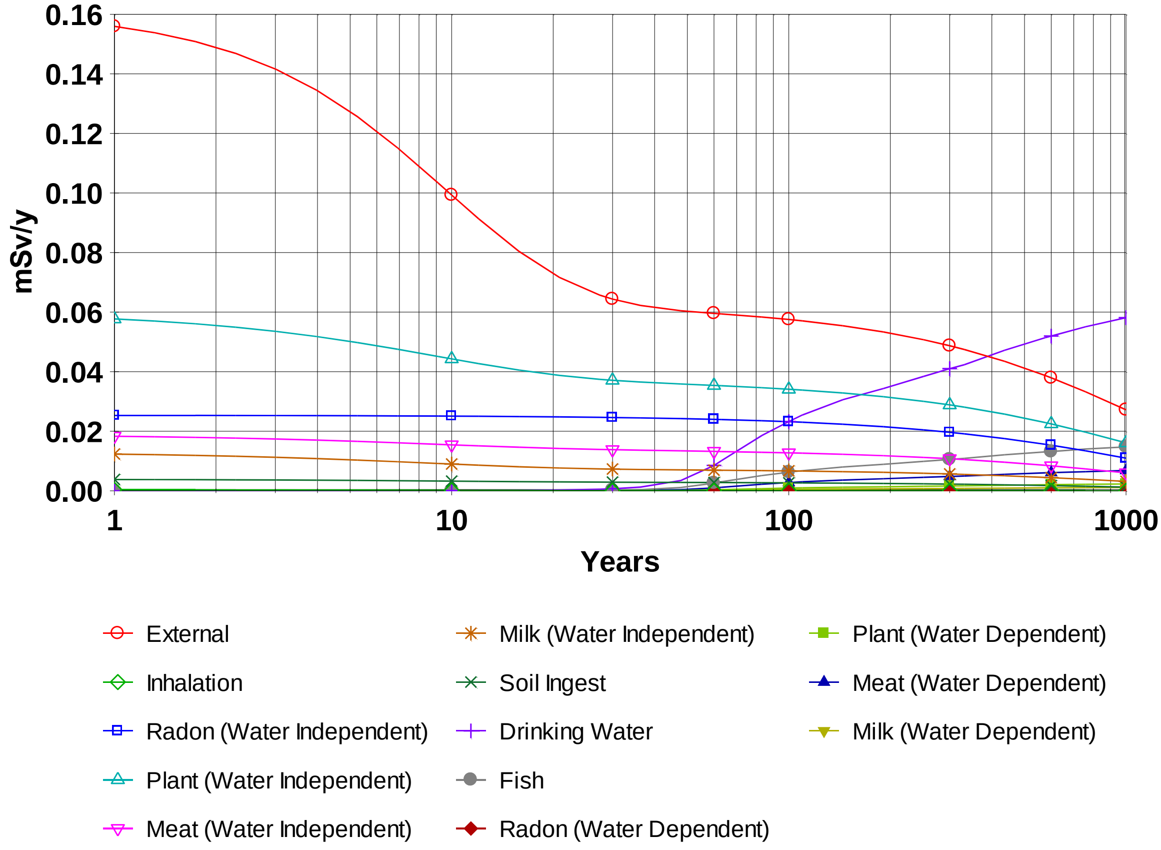

Figure 2: Annual effective dose from various exposure pathways

The radionuclide which gives significant contribution to the total dose received is ^{226}Ra (Fig. 1). In term of exposure pathways (Fig. 2), the external radiation contributed the highest dose followed by plant intake, radon inhalation and meat intake. Contribution from drinking water and fish intake appeared and increased 30 years after disposal but their contribution is very minimum.

Sensitivity Analysis

The estimated total dose received by the critical groups is a function of many variables. In the assessment, the input parameter values were selected based on the best available data obtained from the site. Default or estimated values were used in cases where no site-specific input parameter values available (Yu et al., 1993; Yu et al., 2001). Uncertainty in the values of these parameters introduces an uncertainty in the overall dose estimates. Therefore, in order to evaluate the potential effects of such uncertainty in the critical parameters, a limited sensitivity analysis was performed. Some default or estimated input values were used in this assessment since not all of the input values were site specific. These default values were assessed and chosen to be the most realistic to the condition of the site. However, as a normal practice in any impact assessment, the values chosen in such a way that use of these values in any situation would not result in under estimation of the dose or risk being evaluated (slightly conservative). The input parameter value that has contributed to significant change to the overall dose estimated in the analysis is soil cover depth.

When the soil cover depth was subjected to an increase by a factor 2, the total doses obtained was decreased by 30 %, whereas, a decrease by a factor 2 resulting in an increase in total dose by 25 % as shown in Figure 3. In order for the dose obtained from soil cover depth not to exceed the dose constraint, the minimum cover depth must not be less than 0.05 m.

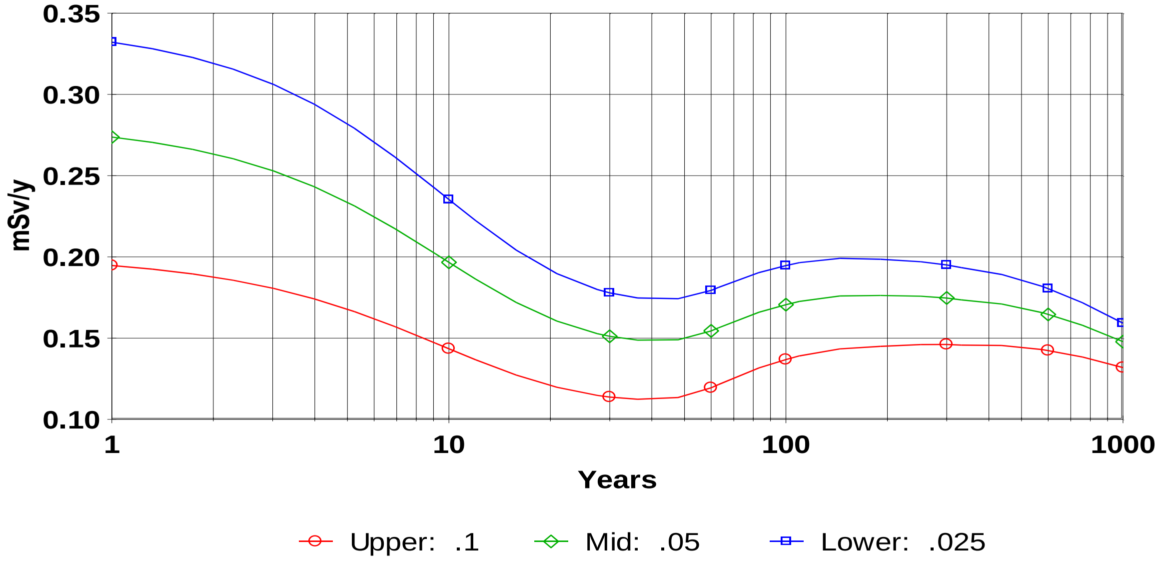

Figure 3: Sensitivity analyses on soil cover depth

CONCLUSIONS

Based on the findings of this study, the estimated dose received by the public is well below the limit as stipulated by AELB i.e. less than 1 mSv/y. The site can be used as a disposal site with treated sludge disposed not exceeding 4 m and the soil cover depth of not less than 0.05 m. The site, once filled with the disposed material, can be released unconditionally without any requirement for future abatement and monitoring measures based on the dose constraint stipulated.

ACKNOWLEDGEMENTS

The authors would like to thank Dr Muhamat Omar and Mr Mohd Yusof Mohd Ali for their technical assistances and support in conducting this study.

REFERENCES

API BULLETIN E2 (BUL E2), April 1, 1992.

Atomic Energy Licensing Board (AELB). (1996). LEM/TEK/30 SEM.2 .

Atomic Energy Licensing Board (AELB). (2009). LEM/TEK/58.

Azlina, M.J., Ismail, B.M., Samudi Yasir, Syed Hakimi Sakuma and Khairuddin M.K. (2003). Radiological impact assessment of radioactive minerals of amang and ilmenite on future land use using RESRAD computer code, *Appl. Radiat. Isot.* 58: 413-419.

Ibrahim, M.Z, Omar, M., Philip, E. and Laili, Z. (2009). Interaction potential between Radium and humic acid, *J. Sains Nukl. Malay*. 21(2): 21-29.

Khairuddin Mohamad Kontol, Syed Hakimi Sakuma and Muhamat Omar. (2007). Radiological Impact Assessment for landfill disposal of NORM wastes in Malaysia. In: *Proceedings of Naturally Occurring Radioactive Materials (NORM) V*, 19-22 March 2007, Spain, 355-359.

Omar, M., Ali, H.M., Abu, M.P., Kontol, K.M., Ahmad, Z., Ahmad, S.H.S.S., Sulaiman, I. and Hamzah, R. (2004). Distribution of radium in oil and gas industry wastes from Malaysia, *App. Rad. Isot.* 60: 779-782.

Omar, M., Ibrahim, M.Y., Hassan, A., Mahmood, C.S., Lau, H.M., Ahmad, Z. and Sharifuddin, M.A. (1991). Environmental radiation and radioactivity levels in Malaysia. In: *IRPA National Seminar, Strategic Sector*, 16-19 December 1991, Pulau Pinang.

Sulaiman, I., Omar, M. and Elias, M.S. (2012). Natural radioactivity of soil in Sabah and Sarawak, *J. Nucl. Relat. Technol*.

Yu, C., Loureiro, C., Cheng, J.J., Jones, L.G., Wang, Y.Y., Chia, Y.P. and Faillace, E. (1993). Data collection handbook to support modelling impacts of radioactive material in soil. ANL/EAIS-8. Argonne National Laboratory, USA.

Yu, C., Zielan , A.J., Cheng, J.J., Le Poire , D.J., Wang, Y.Y., Gnanapragasam, E., Kamboj, S., Arnish, J., Wallo, I.A., Williams, W.A. and Peterson, H. (2001). *User’s Manual for RESRAD Version 6.* ANL/EAD-4. Argonne National Laboratory, USA.