Estimation radiation dose from operation of petroleum NORM waste disposal in landfill using TSD-DOSE

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Abstract. In the petroleum industry, Naturally Occurring Radioactive Materials (NORM) are often enhanced as a result of industrial operation. Radiation protection must be applied in every step of NORM management including disposal. Top rank choice for NORM disposal is landfill. Landfill must provide sufficient protection to both human health and the environment, not only for future but also for operational phase. Landfill workers, including receiving worker, driver and placement worker, are evaluated to estimate potential exposures resulting from landfill operation. Estimation is done for radioisotopes which are of concern in the oil and gas industry, Ra-226, Ra-228, Th-232 and Pb-210. The TSD-DOSE computer code, developed by Argonne National Laboratory, is use to estimate radiological doses to workers from operations at a treatment, storage, and disposal (TSD) facility. The characteristics of the time needed by workers were obtained from observations and discussions with workers at PPLI Cileungsi Hazardous Landfill. Disposal of NORM Waste in bulk form give higher dose than containerized waste. For receiving worker, Ra-226 gives higher dose and for placement worker higher dose arise from Th-232. The size of the vehicle used to transport NORM waste affects the radiation dose received by landfill workers.

1. Introduction

Natural radionuclides from uranium and thorium series are present everywhere in the environment. They are part of soil, rocks, water, and food and can also be detected in the human body. Uranium-238 and thorium-232 are parents of two complex series of radioactive elements, with lead being the last (stable) element in both series. Naturally occurring radioactive materials (NORM) are present in several industries, including the petroleum industry [1].

During oil production, NORM from 232Th and 238U series can be concentrated and accumulated in the form of scale deposits, sludge and produced water. Radium, the predominant radionuclide, can either stay in produced water or co-precipitate with barium forming complex sulphate compounds, carbonates and silicates [2]. The primary radioisotopes of concern in petroleum industry wastes are radium-226 (Ra-226) and radium-228 (Ra-228), which result from the radioactive decay of U-238 and Th-232, respectively, and their associated decay products. The primary radionuclide of concern (ROC) for the gas industry is lead-210 (Pb-210) [3].

There are two ways in which personnel can be exposed to NORM, namely Irradiation, external exposure where the source remains outside the body; and contamination, internal exposure where radioactive...
material is taken into the body via inhalation, ingestion or absorption. Exposure to NORM will not result in acute and severe effects similar to those effects associated with exposure to high radiation levels from man-made sources. Chronic exposure to NORM above exposure limits for the general public or following inadequate safety precautions are typically delayed effects such as the development of certain forms of cancer. A variety of cancers has been associated with exposure to ionising radiation including leukaemia, and cancers of the lung, stomach, oesophagus, bone, thyroid, and the brain and nervous system [4].

NORM management strategy is composed of four components, storage of NORM waste, minimisation of NORM at the source, NORM waste volume reduction, and permanent disposal of NORM waste. The objective is to establish a safe, practical, and cost-effective permanent disposal protocol for NORM waste that provides adequate protection to human health and the environment. Six methods of disposal used elsewhere in the industry were considered. They are landfill disposal, underground injection, land spreading, salt cavern disposal, offshore discharge, and wetlands disposal. These were preliminary ranked against selection criteria which considered risk, technical feasibility, cost, and general acceptance [5].

The Minister of Environment and Forestry Regulation Number P.63/Menlhk/Setjen/KUM.1/ 7/2016 of Requirements and Procedures for Hazardous and Toxic Waste Disposal in the Landfill Facilities, regulate that NORM waste must be disposed of in class I or class II landfills. Although in Indonesia no landfill has been built for the disposal of NORM waste from the petroleum industry.

Radiation dose assessment is needed to determine the estimated dose that workers may receive during landfill operations. TSD-DOSE is designed to process waste-specific and site-specific data to estimate potential radiological doses for on-site workers and off-site public from waste management operations in Transport, Storage and Disposal (TSD) facilities. This code is intended for US-DOE and commercial TSD facilities with a fast and cost-effective method for assessing potential radiation exposure to humans from the treatment of radioactive contaminated waste [6].

In this paper, radiation dose of worker at modeled landfill will be estimated using TSD-DOSE Software. The modeled landfill used is a landfill that is similar to landfill facility at Prasadha Pamunah Limbah Industri (PPLI) Cileungsi, the only one hazardous waste landfill in Indonesia. The workers whose dose is estimated are waste reception workers, drivers in landfills and waste placement workers. The time characteristics required by workers are obtained from observations and discussions with workers in PPLI Cileungsi.

2. Methodology
2.1. TSD DOSE
The dose assessment model TSD-DOSE provides the U.S. Department of Energy (DOE) with a simple, easy-to-use tool for estimating radiological doses to workers and the surrounding public at a commercial treatment, storage, and disposal (TSD) facility for hazardous waste as a result of processing waste slightly contaminated with radionuclides. The dose assessment model has been developed as part of a larger effort to dispose of hazardous waste potentially contaminated with radionuclides and currently stored at several DOE sites.

Seven reference operations that might contribute to radiation exposures for TSD facility workers and the public were developed on the basis of information gathered from the eight previously analyzed TSD facilities. Operations are carried out in the same sequence as those for waste processing, including the following:
- **Transport to a TSD Facility**, for transport of waste to a TSD facility, the transport vehicle is modeled as a flatbed truck carrying 40 drums. The operation consists of four steps: load and secure shipment, drive, rest, perform en route maintenance.
Receiving and Sampling, the receiving and sampling operation involves the activities associated with receiving the waste at the TSD facility, including weighing the vehicle; checking the manifest; and unloading, sampling, and transporting the waste to the storage area. The activities are modeled in five steps: weigh truck, inspect manifest, unload drums, inspect and sample the drums, transfer solids to storage, pump drummed liquids to storage tank.

Storage, the storage operation involves storing the waste prior to incineration or burial. The operation consists of three steps: work in solid waste storage area, transfer solids, work in liquid waste storage area.

Incineration, the incineration operation models the incineration of waste and the removal of ash and loose plateout, but it does not include removal of plateout from the kiln walls, which is modeled in the incinerator maintenance operation. Incineration consists of four steps: incinerate waste, collect residue in bin, transport bin to storage area, transport bin from storage area.

On-Site Landfill, the on-site landfill operation includes the activities leading to burial of the waste or residues from incineration in an on-site landfill. The actual burial of the waste at the landfill is not included because of the amount of shielding (i.e., bulldozer and 8 in. of soil) between the worker and the source. This operation consists of four steps: unload waste to mixing pit, mix waste in mixing pit, load truck and transport waste to landfill, unload truck at landfill.

Transport to Off-Site Landfill, the transport to off-site landfill operation involves transporting the incineration residues to an off-site landfill for burial. The operation consists of four steps: load and secure waste, drive, rest, perform en route maintenance.

Incinerator Maintenance, the incinerator maintenance operation involves removing plateout from the inside of the kiln and consists of only one step. The activities involved in this operation include using jackhammers to remove the plateout and bricks from the interior of the kiln and removing the debris. The assumption is made that the dust generated by the removal of the plate out results in an internal dose to incineration workers.

The TSD-DOSE model estimates doses to workers and the off-site public from treatment, storage, and disposal of waste contaminated with small quantities of radionuclides. The on-site TSD facility receptors include drivers, receiving workers, incinerator workers, landfill workers, and the collective worker population. Off-site receptors are analyzed for both individuals and populations living within 50 miles of the TSD facility [6].

2.2. Modeled Landfill

The modeled landfill used is a landfill that is similar to PPLI Cileungsi, the only one hazardous waste landfill in Indonesia. PPLI Cileungsi began operating in 1994 and cell 1 was closed in 2012, so the operating time is 18 years. The landfill design used in this study has an area of 6.3 Ha and a waste thickness of 12.5m. So if a practical approach is used, each year landfills can receive 43,750 m$^3$. This is done because the calculation in TSD-Dose on a 1-year basis. Using the assumption that the waste density is the same as the dried sludge density of 1.39 g/cm$^3$ [7], then in one year there are 60,812 tons of waste. Modeling will use 1 Bq/ram activity concentration for each radionuclide (Ra-226, Ra-228, Th-232 and Pb-210) to find the radiation dose.

The workers whose dose is estimated are waste reception workers, drivers in landfills and waste placement workers. Modeling is done for two types of waste packaging, bulk waste without packaging, and containerized waste. This is done to examine how the exposure pathway through breathing influences the dose received by the worker. For bulk the particulate content in the air is considered, in TSD-DOSE the value is 1 mg/m$^3$. 

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Table 1. TSD-DOSE Input Parameters

| Parameter                           | Input TSD-DOSE          |
|-------------------------------------|-------------------------|
| waste reception workers:            |                         |
| waste unloading time                | 20 minutes              |
| sampling time                       | 30 minutes              |
| driver:                             |                         |
| transport time to landfill          | 10 minutes              |
| vehicle size                        | 15 ton (5.8 x 2.3 x 1.6 m) |
| waste placement workers:            |                         |
| placement time                      | 20 minutes              |

The time characteristics required by workers are obtained from observations and discussions with workers in PPLI Cileungsi, that shown in Table 1. Onsite transportation of waste using arm roll trucks with a capacity of 15 ton, and size 5.8 x 2.3 x 1.6 m. To find out the effect of the size of the transport vehicle, a simulation using an arm roll truck with a capacity of 9 ton (4.0 x 2.1 x 1.4 m) and 12 ton (4.8 x 2.3 x 1.4 m).

3. Result and Discussion

Estimated annual dose that received by worker as shown in Table 2 and Table 3. The highest dose is obtained by waste placement worker with bulk form. This finding is difference with study in North Dakota that highest dose is obtained by waste reception workers. But the same fact is that for waste reception workers, the Ra-226 gives a higher dose and for placement workers, higher dose arise from Th-232.

Disposal of NORM waste in containerized form reduces the radiation dose of Pb-210 and Th-232 radionuclides. The dose of Pb-210 radionuclide can be reduced from 1.9x10^{-3} mSv/year, to 4.4x10^{-5} mSv/year. While the Th-232 radionuclide dose can be reduced from 12.3x10^{-1} mSv/year to 4.6x10^{-6} mSv/year.

Table 2. Estimated annual dose that received by worker with bulk waste

| Dose (mSv/year) | Ra-226 | Ra-228 | Pb-210 | Th-232 |
|-----------------|--------|--------|--------|--------|
| Driver          | 5.60x10^{-2} | 3.00x10^{-2} | 2.20 x10^{6} | 1.40 x10^{6} |
| waste reception workers | 6.90x10^{-2} | 3.70x10^{-2} | 2.80 x10^{6} | 1.80 x10^{6} |
| waste placement workers | 2.60 x10^{-1} | 1.40 x10^{-1} | 3.80 x10^{-1} | 4.50 x10^{-1} |

Table 3. Estimated annual dose that received by worker with containerized waste

| Dose (mSv/year) | Ra-226 | Ra-228 | Pb-210 | Th-232 |
|-----------------|--------|--------|--------|--------|
| Driver          | 5.60 x10^{-2} | 3.00 x10^{-2} | 2.20 x10^{6} | 1.40 x10^{6} |
| waste reception workers | 6.90 x10^{-2} | 3.70 x10^{-2} | 2.80 x10^{6} | 1.80 x10^{6} |
| waste placement workers | 2.50 x10^{-1} | 1.40 x10^{-1} | 4.40 x10^{-5} | 5.00 x10^{-6} |
Simulations to find out the effect of the size of the transport vehicle are done by using difference vehicle size, arm roll truck with capacity 9 ton and 12 ton. Smaller vehicle gives higher dose to all landfill workers. This is because the smaller the size of the vehicle the more transportation occurs so the exposure time is greater. Estimated annual dose that received by worker using 9 tons capacity arm roll truck as shown in Table 4, and using 12 ton capacity arm roll truck as shown in Table 5.

| Table 4. Estimated annual dose that received by worker using 9 ton arm roll truck |
|------------------------------|----------------|----------------|----------------|
| Dose (mSv/year) | Ra-226 | Ra-228 | Pb-210 | Th-232 |
| Driver | 7.70 x10\(^{-2}\) | 4.20 x10\(^{-2}\) | 3.50 x10\(^{-6}\) | 2.00 x10\(^{-6}\) |
| waste reception workers | 1.00 x10\(^{-1}\) | 5.40 x10\(^{-2}\) | 3.60 x10\(^{-6}\) | 2.70 x10\(^{-6}\) |
| waste placement workers | 3.40 x10\(^{-1}\) | 1.80 x10\(^{-1}\) | 7.10 x10\(^{-3}\) | 8.40 x10\(^{-1}\) |

| Table 5. Estimated annual dose that received by worker using 12 ton arm roll truck |
|------------------------------|----------------|----------------|----------------|
| Dose (mSv/year) | Ra-226 | Ra-228 | Pb-210 | Th-232 |
| Driver | 6.50 x10\(^{-2}\) | 3.50 x10\(^{-2}\) | 2.70 x10\(^{-6}\) | 1.60 x10\(^{-6}\) |
| waste reception workers | 8.20 x10\(^{-2}\) | 4.40 x10\(^{-2}\) | 3.60 x10\(^{-6}\) | 1.80 x10\(^{-6}\) |
| waste placement workers | 3.10 x10\(^{-1}\) | 1.70 x10\(^{-1}\) | 5.40 x10\(^{-3}\) | 6.40 x10\(^{-1}\) |

4. Conclusion
Dose from NORM waste with activity concentration 1 Bq/gram for Ra-226, Ra-228, Th-232 and Pb-210 do not exceed dose limit for public, 1mSv/year. Disposal of NORM Waste in bulk form give higher dose than containerized waste. So, containerization of waste is necessary to reduce radiation dose. For receiving worker, Ra-226 gives higher dose and for placement worker higher dose arise from Th-232. The size of the vehicle used to transport NORM waste affects the radiation dose received by landfill workers. Smaller vehicle gives higher dose to all landfill workers, so avoid small vehicle to transport waste from processing facility to the landfill.

5. References
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