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Estimation of radiation dose for gold mine workers working with nuclear gauges and external ionizing radiation exposure during cargo radiographic inspections in Ghana

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ABSTRACT

Absorbed dose rate and annual effective dose estimated for occupational workers for Goldmines in Ghana that uses nuclear gauges in their operations and external ionizing radiation exposure during cargo radiographic inspections were measured as part of the authorization process for the use of ionizing radiations sources in Ghana. The measurements reported in this paper were made with portable radiation monitor which employed GM tube and was calibrated against secondary standard dosimetry system and a data for a five-year period (2010-2014) was compiled from the RAIS of the Ghana Radiation Protection Board. The average absorbed dose rate in air for Goldmine workers was 0.73µSv/h with an annual effective dose of 1.45 mSv while the average external radiation dose for workers and members of the public during cargo inspection was 0.23 µSv/h for Cobalt 60 scanners and 0.1 µSv/h for x-ray scanners and the annual effective dose for both workers and members of the public for Cobalt-60 and X-ray scanners were 0.46mSv and 0.2mSv respectively. It was concluded that the prevalent radiation levels did not pose any significant radiological health hazard to workers and members of the public.

Introduction

Background

All ionizing radiation equipment is subject to licensing by the national regulatory authority and must conform to national and international radiation safety regulations and requirements. The primary purpose of radiation surveys is to identify the magnitude or verify the absence of dose rates so that personnel exposure to radiation is maintained As Low As Reasonably Achievable (ALARA). In some mining and mineral processing operations workers may be exposed to naturally-occurring sources of radiation in the work environment, including radiation from mined or processed materials. At some sites and for some workers, exposures may also arise from equipment containing human-made radioactive sources, such as thickness and density gauges, and from radiation generators, such as X-radiography equipment **[1, 2].**

Nuclear gauges

Nuclear measurement gauges for industrial process measurements have been around for many years. They have been a mainstay in making the most difficult level, density, bulk flow, and moisture measurements. Nuclear measurement gauges' work where no other technology will. They give excellent performance under hostile and rugged conditions. High temperatures, pressures, and other difficult industrial processes usually pose no problem for a nuclear measurement gauge. Despite thousands of satisfied users of this technology worldwide, nuclear measurement gauges are sometimes a pariah to companies and their employees. From many companies' perspective, the move to be more environmentally friendly has sometimes superseded the facts about nuclear gauges, their benefits to process operations, and most important, the safety and environmental issues surrounding this measurement technology **[3].**

Many industries use nuclear measuring gauges that incorporate a sealed source containing a radioactive nuclear substance and because we know the penetrating power of the radiation emitted by specific substances, nuclear gauges provide an inexpensive, yet highly reliable and accurate method of measuring the thickness, density or make-up of a wide variety of materials or surfaces. There are two types of nuclear gauges, fixed and portable. Fixed gauges are most often used in mines, mills and production facilities to provide precise measurements of thickness, density or quantity and as a way of monitoring a production process and ensuring quality control. These fixed gauges house a sealed source that contains a radioactive nuclear substance.

Each nuclear gauge uses one or two small radioactive sources such as cesium-137, americium beryllium-241, radium 226 or cobalt 60. The source's strength is measured in terms of how much radiation it emits. Although these sources are physically quite small, they are often extremely powerful and highly radioactive. However, it is the amount of radiation you absorb, not the strength of the source that can pose a danger to your health. The amount of radiation absorbed is controlled by the source shielding and by proper handling techniques. Nuclear gauges are as safe as using a power saw or a welding torch. As with those tools, safety precautions must be taken. However, since the potential harm from radiation is not as obvious as the danger from a sharp blade or a flame, the safety precautions are not obvious either.

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By following a few simple rules, you can be assured that working with or around nuclear gauges will pose no threat to your health and safety. Gauges must be checked regularly to ensure that the source is secure within its capsule and that there is no leakage. Every 12 months, the licensee must arrange for the regulatory body to perform these leak tests and dose rate measurements. The licensee will receive a leak test and dose rate certificate showing the results. Any device that is found to have a leaking source must be removed from use and the regulatory body must be notified immediately. A small amount of radiation always penetrates the gauge housing and can be detected using a sufficiently sensitive radiation detector even if the source capsule is intact. This low level radiation poses no significant health risk. Conditions of the license further control the use and handling of the gauges. To ensure that license conditions and GRPB Regulations are being followed, the GRPB may perform both Type I inspections (audits) or Type II (compliance) inspections. These inspections are also used to confirm that the licensee is implementing an effective radiation protection program consistent with regulatory requirements. In order to ensure complete safety with nuclear gauges, you must, as with any type of equipment, follow the operating instructions. Additional radiation safety training should be done for all workers using the radiation devices. This should include basic radiation safety, information about the specific nuclear substances involved, methods of keeping doses ALARA, review of the license and its conditions, and review of the Nuclear Safety and Control Act and the pertinent regulations. Specific transportation training should be done and Transportation of Dangerous Goods (TDG) training certificates issued if required. Radiation safety awareness training should be provided to workers who are not necessarily gauge users but who may work in the proximity of nuclear gauges. It is recommended that refresher training be done every 3 to 5 years. The regulatory dose limits for workers are 50 mSv per year and 20 mSv average over a five-year period **[4].**

Scanners

The use of ionising radiation for cargo scanning purposes can be justified on the grounds that any radiological risk is trivial and is far outweighed by the societal benefits that scanning can bring. Customs and other enforcement agencies have increasingly turned to X-ray and gamma scanners to screen import and export consignments**. [5]**

Effective customs, border, port and other inspection authorities increasingly use gamma and

x-ray non-destructive (non-intrusive) inspection technology (NDT) in order to produce high quality interior images of commercial vehicles with or without cargo inside. Ionizing radiation

easily penetrates cargo and closed containers. The purpose of this scanning is to fight theft,

reveal contraband and has been used as valuable tool in the fight against cross-border smuggling, the number of commercial vehicles being scanned has dramatically increased. Therefore, inspection authorities consider scanning tools as an efficient complement to their cumbersome work of manual inspections.

An X-ray is an electromagnetic wave of very short wavelength. X-rays are polychromatic and have a larger spectrum than gamma rays. The power source for X-ray systems is electrical. This means it can be turned on and off. It also means that in a site where the electricity supply is not certain, it is essential to have a back-up generator. The energy level of X-ray systems is measured in mega-electron volts (MeV). The MeV rating varies between fixed, mobile and relocatable system. For the purpose of container scanning the maximum X-ray energy is 9 MeV. X-ray systems are considered to provide better image quality but are more expensive and, in general, are physically larger than Gamma Ray systems.

Gamma rays are monochromatic electromagnetic waves of shorter wavelength than X-rays. Gamma rays are produced from natural isotopes such as Cesium-137 and Cobalt-60. These are radioactive sources and the energy emission is continuous, because of this the isotopes must be kept in a shielded cabinet at all times. Over time, the radioactive isotopes decay and ultimately require replacement, usually every 5 years. Some Members that operate these systems have included within their contracts a provision for periodic testing to ensure that energy levels remain sufficiently high. Contracts should include supplier “take back” provisions for spent sources. Gamma ray systems are cheaper to purchase and to operate but the images produced may be more difficult to interpret. A gamma ray unit is, in general, smaller than an X-ray unit which gives these systems a higher degree of mobility. Gamma ray units are more likely to be mobile or relocatable than fixed. A common comparative method for systems is to refer to steel penetration capability. A gamma based system using a Cobalt-60 radioisotope, which has greater penetration capability than one based on Cesium-137, is said to penetrate up to 165mm of steel. Manufacturers of X-ray equipment show 180mm penetration of steel for a 2.5 MeV mobile X-ray system, over 200 mm for a 3.0 MeV mobile unit and up to 350mm for a 6.0 MeV relocatable unit. Fixed X-ray systems of 9 MeV are able to penetrate up to 450 mm of steel. Some currently deployed mobile systems have energy levels as low as 300/450 Kev and are inadequate for the effective screening of typical container traffic. Members who currently use X-ray systems are of the view that - 3 MeV is the minimum energy level required for effective cargo penetration. However, steel penetration is not the sole criterion to achieve high quality X-ray images. Spatial resolution and contrast sensitivity are other important factors to be taken into account **[6].**

Principles of Radiation Protection

Three factors come into play when protecting yourself from the effects of radiation. The less time a person remains in the area of radiation, the lower the radiation dose that person will receive. Work should be carried out quickly and efficiently, but with attention to safety. The intensity of radiation and its effects fall off sharply as you move further away from the radioactive source. The dose rate decreases as the inverse square of the distance from the source. For example, by moving twice as far away from a radioactive source, you are exposed to one-quarter the amount of radiation; moving three times as far away means one-ninth the exposure, and so on. Protective material placed between you and the source reduces the level of radiation to which you are exposed. The source, in its capsule, is inserted into the gauge’s source housing, which shields the radiation emitted from the source.

Licensed users of nuclear gauges must ensure that doses are kept ‘as low as reasonably achievable’ (ALARA). The Ghana Radiation Protection Board (GRPB) facilitates this by regulating the use of radiation devices, by assessing radiation protection programs, and by regularly inspecting licensees to ensure compliance with the regulations and license conditions. The GRPB also sets limits on the amount of radiation to which you may be exposed, depending on your job. Any worker who is required to perform duties with a reasonable probability of receiving a radiation dose greater than 1 mSv per year must be designated as an occupational Worker.

Personnel Monitoring

There are two common methods of determining the radiation doses received by persons working with radiation emitting devices. Portable gauge users may estimate their total dose based on the number of measurements performed in a year. Using the number of measurements performed in a year multiplied by an estimate of the dose received per measurement can give an estimate for the total radiation dose received. Dose estimates can be done for fixed gauge users as well by multiplying the hours of work in proximity to the gauge by the dose rate in their work area.

Alternatively, the licensee may choose to monitor their workers using a personal measuring device called a "dosimeter". The most commonly used type of dosimeter for gauge users is the thermoluminescent dosimeter, or "TLD". TLDs contain small chips of material that absorb radiation in a measurable form. They should be worn between the waist and neck area. They should not be exposed to high temperature or water, or left in direct sunlight. When not being worn, they should be stored in a low radiation area away from the gauges. TLDs are read by agencies licensed by the secondary standard dosimetry laboratory of the GRPB.

This study was done in gold mining companies where they use nuclear gauges in their operations and some scanning companies at the Ghana Ports and Harbors. The objective of the present study was to assess the dose received by goldmine workers who work close to the nuclear gauges and also is to investigate the hazards and risks associated with transport activities which are unavoidably connected with the possible exposure of drivers and other employees to ionizing radiation while undergoing the cargo scanning process. A detailed radiation survey was made by using a quite sensitive and well calibrated radiation dose rate meter and the dose rate measurement over a five-year period (2010-2014) was compiled from the RAIS of the radiation Protection Institute, Ghana Atomic Energy Commission **[7].**

Description of Study Area

Ghana lies between latitudes 4° and 12°N. The southernmost part of Ghana lies in the region, at Cape Three Points near Busua, in the Ahanta West District. South Ghana contains evergreen and semi-deciduous forests consisting of trees such as mahogany, odum, and ebony. The Western Region covers an area of approximately 2,3921 square kilometres, which is about 10 per cent of Ghana's total land area. The region has about 75 per cent of its vegetation within the high forest zone of Ghana, and lies in the equatorial climatic zone that is characterized by moderate temperatures.

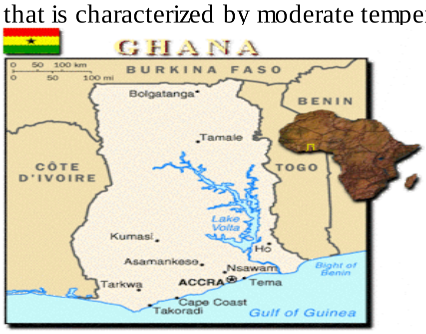

Fig1. Map of the study area.

It is also the wettest part of Ghana with an average rainfall of 1,600mm per annum. It is bordered on the east by the Central Region, to the west by the Ivory Coast (Côte d'Ivoire), to the north by Ashanti and Brong-Ahafo Regions, and to the south by the Gulf of Guinea **[8].**

Materials and Methods

Radiological monitoring was performed by using a Universal survey meter, manufactured by Rados Technology OY Finland, Model Rados 120 and a serial number 210071. It employed a GM tube as the active detector having energy independent response from 50 keV to 3 MeV. The measurement with Rados 120 universal survey meter, owing to the instantaneous results and the easily portable nature with almost nil trans port charges, was preferred over thermoluminescent dosimeter (TLDs) technique which required longer exposure times (in months) to record background radiation levels and thereafter required the indirect evaluation of the results in the laboratory. The reliability of the dose rate meter results was assured by its calibration in the Secondary Standard Dosimetry Laboratories (SSDL), Radiation Protection Board Ghana, whose measurements is traceable to Primary Standard and is ensured by the International Atomic Energy Agency (IAEA) through the postal dose inter-comparison **[9].**

Dose rate records from the Regulatory Authority Information System (RAIS) of RPB from 2010 to 2014 of ten (10) Gold mining companies in the western region of Ghana, three cobalt 60 scanners and one X-ray scanner at the ports and harbors of Ghana were used for this purpose and their mean value was converted to the absorbed dose rate in air **[10].** The minimum, maximum, and mean value of the absorbed dose rate in air and the effective annual dose derived from these measurements are mentioned in tab. 1.

Table1. Environmental Gamma Radiation Levels Around Nuclear Gauges in Gold Mining Companies, Ghana.

Goldmine coded	Average Absorbed dose rate in air [μSvh^{-1}]	Annual Effective dose [mSv]
Goldmine A	0.43	0.86
Goldmine B	1.25	2.50
Goldmine C	1.05	2.10
Goldmine D	0.77	1.54
Goldmine E	0.77	1.54
Goldmine F	1.60	3.20
Goldmine G	0.25	0.50
Goldmine H	0.32	0.64
Goldmine I	0.11	0.22
Goldmine J	0.72	1.44
Minimum	0.11	0.22
Maximum	1.60	3.20
Average	0.73	1.45

The average absorbed dose rate in air, D, was calculated from direct measurement from the Rados 120 universal survey meter(μSvh^{-1}) at one (1) meter around the nuclear gauge and also at specific positions of scan areas at the ports and harbors of Ghana and an annual working time or occupancy factor of 2000 hours for occupational workers.

The annual effective dose, AED, considering 2000 hours for a radiation worker in a year was estimated using the following conversion **[11].**

AED [mSv] = $D(\mu Svh^{-1}) \times 2000(h) \times 10^{-3}$ where D is the dose rate in μSvh^{-1}

Fig 2. A view of Rados 120 Universal dose rate meter used during the study.

Table 2. External ionizing radiation exposure during cargo radiographic inspections.

Scanners Coded	Average Absorbed dose rate in air [μSvh^{-1}]	Annual Effective dose [mSv]
Cobalt-60 Scanner A	0.20	0.40
Cobalt-60 Scanner B	0.27	0.54
Cobalt-60 Scanner C	0.22	0.44
Minimum	0.20	0.40
Maximum	0.27	0.54
Average	0.23	0.46
X-Ray Scanner	0.1	0.20

Results and Discussion

As shown in tab. 1, the absorbed dose rate in air at the mining site where nuclear gauges have been mounted has been found to vary from 0.11μSv/h to 1.60μSv/h with the mean value of 0.73μSv/h. The annual effective dose for the ten mining companies ranges from 0.22mSv to 3.20mSv and the mean annual external effective dose comes out to be 1.45 mSv which is less than 20mSv recommended by ICRP for radiation workers. The higher dose rate measurement of Goldmine D, E and J was due the higher activity concentrations of the nuclear gauges used at the mining site.

Similarly in tab. 2 the mean absorbed dose in air for Cobalt 60 scanners was 0.20μSv/h and 0.1 μSv/h for the X-ray scanner while the mean annual effective dose for both workers for Cobalt-60 scanners and X-ray scanners were 0.23mSv and 0.46mSv respectively which is less than both the 20mSv and 1mSv recommended by ICRP for radiation workers and members of the public but relatively workers and members of the public around the Cobalt-60 scan are likely to receive more radiations than those at the X-ray scan due to the difference in operation of the scan.

Conclusions

The annual effective dose for radiation workers in mining companies where nuclear gauges are involved in their operations, radiation workers at the scan and members of the public are below the annual dose limit of 20mSv and 1mSv respectively. Any worker who is required to perform duties with a reasonable probability of receiving a radiation dose greater than 1 mSv per year must be designated as an occupational worker especially workers in Goldmine D, E and J must be monitored to eschew stochastic effect of ionizing radiations. Also workers and members of the public especially drivers around the Cobalt 60 scan must adhere to the principles of radiation protection to keep their doses As Low As Reasonably Achievable. Finally, the annual effective dose for radiation workers in the ten mining companies, radiation workers and members of the public of the cargo scan are below the limits recommended by the International Commission for Radiological Protection which assures the safety of workers and the general public.

Recommendation

For any future work in the same area, it is recommended that the effective dose rate should be estimated for workers during repair and maintenance. Radiation Workers should also bear in mind that the dose a person received from external radiation is directly proportional to the length of time spent in a radiation field. Therefore, minimizing the amount of time spent in a radiation field will minimize the dose. It is also recommended that Radiation safety awareness training should be provided to workers who are not necessarily gauge users but who may work in the proximity of nuclear gauges and drivers who are mostly around the scan area and that refresher training be done at least every 3 to 5 years to aid old and new workers to keep doses As Low As Reasonably Achievable (ALARA).

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