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Analysis of Dose Distribution for the Gamma Krypton -85 Irradiation in Normal Conditions with Estimation of Cancer Risk Factor. A Case Study

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Abstract

The aim of this work is to protect the workers from exposure to the ionizing radiation where one of principles of radiation protection is estimating the doses which workers are exposed. These doses must be under Individual Dose Limitation. The annual limits allowed by the competent national authorities shall be established taking into account the limits established by the International Atomic Energy Agency. The dose distribution at the working place, one of the Egyptian companies in Alexandria to produce medical products, for measuring plastic thickness was experimentally and theoretically determined. RadPro Calculator Version3.26 was used to calculate the dose distributions in normal operation. The dose distribution inside the unit was measured during the operation by using AD6-6150 Automess Survey Meter and Survey Meter-Inspector EXP+ (for measuring gamma). The comparison between measuring and theoretical results has been done. Theoretical and measuring data obtained have been compared with IAEA safety standard (GSR-part 3). The results indicate good agreement between the measurements and theoretical calculation. Where at 10cm from the source, the effective dose rate was (6.5μSv/h) theoretically. The average measured effective dose rate at the same distance (the nearest distance to the source) was (7.45-7.40 μSv/h).This means that the theoretical and measured readings are convergent and lower than the effective dose rate. The measured effective dose rate was done by Direct Reading Pocket Dosimeters with average of (7.0 μSv/h). For occupational exposure of workers over the *age of 18 years, the effective dose rate was (10μSv/h) or (20mSv/y).The risk factor has been calculated and the obtained data was the lifetime risk of cancer death is nearly 5% per man-sievert for persons in working age i.e. 0.0891 man may have cancer from this dose when workers exposed to Kr-85 source with activity (200mCi) after (10 years).*

Key words: irradiation, effective dose, Krypton-85, radiation protection, risk factor.

INTRODUCTION

Radiation and radioactive substances have many beneficial applications, ranging from power generation used in industry, medicine and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

In industrial applications the irradiation uses, for instance, foods, medical equipment, and other substances are exposed to certain types of radiation (such as x-rays) to kill germs without harming the substance that is being disinfected and without making it radioactive. Also, radiation is used to help in removing toxic pollutants, such as exhaust gases from coal-fired power stations and industry. The agricultural industry makes use of radiation to improve food production and packaging. Plant seeds, for example, have been exposed to radiation to bring about new and better types of plants. Additionally, fluid levels in oil and chemical tanks, and the moisture and density of soils and material at construction sites. Gauges containing radioisotopes is also used in many other industrial applications such as the thickness of paper products and plastic. The harmful effects of the radiation fall into two categories, non- stochastic & stochastic effects. Non-Stochastic effects are deterministic in nature and do not occur below a particular threshold radiation dose. Severity of these effects increases with increase in dose received. Stochastic Effects do not have any threshold dose and are probabilistic in nature. Incidence of these effects increases with the dose received. Stochastic effects occur due to small exposure received over long period that may cause cancer. Studies of workers in radiation-related occupations provide an opportunity to assess the health risks of low-dose ionizing radiation exposure. For most applications in occupational or medical (research) situations, stochastic risks of cancer induction are the principal ones to consider. The effective dose concept was developed by the ICRP and provides a single measure of the dose to a reference person (of average age, gender and nationality) that is roughly proportional to the total 'radiation detriment' from stochastic effects associated with the exposure.

Exposure to radiation may cause cancer and other health problems. But in most cases, the risk of getting cancer from being exposed to small amounts of radiation is small. The chance of getting cancer varies from person to person. It depends on the source and amount of radiation exposure, the number of exposures over time, and the age at exposure. In general, the younger age at exposure to radiation, the greater the risk of cancer. Exposure to small amounts of radiation doesn't cause any symptoms. But exposure to large amounts all at once may cause radiation sickness and death. You can't avoid radiation that occurs naturally. But there are some things can be done to reduce the exposure to man-made sources [1].

ICRP-37 reported the (cumulative) effective dose of radiation exposure over 12 months is given.

An effective dose of 20 mSv per year is in the same category as a lens equivalent dose of 150 mSv/year, a skin dose of 500 mSv per year (averaged per exposed cm^2) and effective doses to hand, feet and ankles of 500 mSv per year.[2,3] The Effective dose with corresponding risk category and associated level of benefit where, this category represents a low level of risk. The range of 1 to 10 mSv corresponds with a maximum risk of one in ten thousand, and is of the same order of magnitude as the annual natural background radiation in some parts of the world. In addition, it is not an uncommon for radiological workers to receive this dose on an annual basis.[4]In recent years, a number of international bodies have developed radiation risk models, which allow for calculation of the Lifetime Attributable Risk (LAR) of radiation induced cancer and mortality as a function of effective dose, age and gender of the exposed reference person .BEIR VII published a LAR for incidence of all cancers of 0.012% per mSv and a LAR for mortality from all cancers of 0.006% per mSv (averaged over both genders and all ages in the USA population).[5,6,7,8]

External gamma risk coefficients for krypton-85 source were used to estimate lifetime cancer mortality risks for submersion in krypton clouds. If it is assumed that krypton releases occurred and 100,000 people were continuously exposed to a cloud of air with an average concentration of 1 pCi/cm3 over a period of one year, then the estimated number of fatal cancers in this group of 100,000 would be less than 1 for krypton-85. (This is in comparison to the 25,000 people from this group who would be predicted to die of cancer from all other causes per the U.S. average.) .This risk is due to the beta particles and gamma rays associated with the krypton isotope. The goal of radiological prevention is to avoid the inevitable effects by setting dose limits below the threshold of these effects and minimizing the random effects to a minimum achievable. The aim of this study is to protect the workers from exposure to the ionizing radiation from ^{85}Kr source (which used in industrial applications such as the thickness of paper products and plastic. This has been done by doses after the workers already exposed to radiation (gamma rays) to know if these doses within available radiation worker doses or not. Basic principles in radiation protection are 1-Justifications of practice,2-Optimization of Radiation Protection (this principle is called As Low As Reasonably Achievable or ALARA principle) and 3-Individual Dose Limitation. The direct dangerous on workers who measure plastic thickness industrially is gamma emission from sealed gaseous beta-shielded ^{85}Kr source. This technique used for producing medical bandages helpful in covering different kinds of wounds. The dose distribution at the working place for measuring plastic thickness was experimentally and theoretically determined. The simple method for thickness detection is an ATI gauge which uses the attenuation of beta particles to measure the thickness or weight of various materials, such as plastics and paper, and metal.[9]Thickness gauge is a non-contact and non-destructive thickness gauge measurement systems to check the quantity measurement of the material on rolling mills. The system continuously monitors the thickness parameter (sheet thickness) of the material on both side of the mill. The deviations from preset target values are instantly detected allowing immediate corrections to the production process to maintain uniform thickness. All relevant measuring results are evaluated and displayed graphically on a monitor and documented by hard copy.[10,11]

Figure (1) shows the process control of plastic thickness. The spacing of the rollers that determines the thickness of the sheet of plastic is controlled by a device that takes into account the paper thickness measured from the attenuation of the beta electron beam of a radioactive source. The use of beta radiation is adapted to the obstacle formed by the paper. Gamma rays would cross it also easily while alpha rays would be absorbed before reaching the detector. Due to the penetration power of radiations such as gamma or beta, direct contact of the object to be tested with the source or the detection device is not necessary. This allows non-destructive measurements in real time, while the matters to be followed undergo the steps of an industrial process.

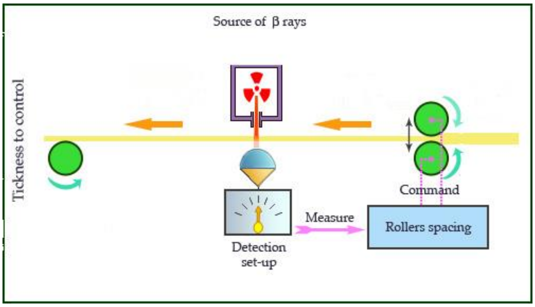

Figure (1): process control of the paper (or plastic) thickness.[11]

MATERIAL AND METHOD

One of the Egyptian companies in Alexandria to produce medical products, ATI's (Auto Tech Interiors) gauges can be used for measuring coat weight, basis weight, thickness, and detection. A beta gauge consists of two basic components, a source of radiation and a radiation detector. The web to be measured is placed between the source and detector. In addition, a measurement, the illustration below shows the basic setup: Beta particles are nothing more than fast moving electrons, emitted from certain radioactive isotopes, called sources. Compared to gamma rays, beta particles are much safer because they do not travel as far, and they are easily stopped by several feet of air, or thin plastics. This makes it quite easy to install a shield around the gauge, if personnel are working nearby. In addition, ATI uses very small activity (size) sources. Conventional beta gauges use an ionization chamber to detect the beta particles. Conventional beta gauges use sources with hundreds or thousands of mille-curies of activity. This substantially reduces the amount of radiation present around the gauge. When they strike material, some of them will pass through, while others will be stopped. The thicker (or more dense) the material, the greater the chance a particle will be stopped. By measuring the ratio of the number of particles that pass through the material to the number without any material, the thickness (or weight) of the material can be determined.[12].

BTG-3000 is a machine, using Krypton-85 (radioactive source), for measuring plastic thickness. This machine is using PLC (Programmable Logic Controllers) and HMI (Human Machine Interface). If there is any trouble, this machine will indicate where the problem is. Instruments like Thickness gauge, with QCS (Quality Control Systems) are manufactured for industries like Plastic films. System Measures various parameters with high accuracy at online production lines and mills by electronic non-destructive and non-contact gauge instruments.

Product description:

The measuring principle is based on the attenuation of beta radiations emitted by a source as it passes through a material. The thickness basis weight is determined by sensing variations in the energy radiated by the source of known intensity. The measurement is continuous online and therefore useful as feedback for automatic control. Figure (2) represents the Plastic Thickness Gauge BTG 3000machinewhichhas provided the measurement of the Plastics thickness whether the process is film extrusion, sheet, co-extrusion, blown film, cast, bi-axial or a range of other process methods. Plastic thickness gauge display and control thickness for cross web, machine direction profiles along with trends, product recipe and roll reports.

Figure (2): Quality Control System for plastic machine.[13]

Krypton 85 (^{85}Kr):

Krypton-85 is a radioisotope of krypton element. Krypton is a colorless, odorless, tasteless gas about three times heavier than air. Krypton is generally inert and forms very few chemical compounds. The major source of krypton-85 is nuclear fission. It has a half-life of 10.756 years and maximum decay energy of 687 keV. It decays into stable, non-radioactive rubidium-85. Its most common decay (99.57%) is by beta particle emission with maximum energy of 687 keV and an average energy of 251 keV. The second most common decay (0.43%) is by beta particle emission (maximum energy of 173 keV) followed by gamma ray emission (energy of 514 keV). Other decay modes have very small probabilities and emit less energetic gammas. There are 33 other known isotopes of krypton. Krypton-85 is a medium energy beta source. It is suitable for measurements in the range of 150 to 1500 GSM (grams per square meter). Krypton-85 is allowed to penetrate small cracks, and then its presence is detected by autoradiography. The method is called "krypton gas penetrant imaging". The gas penetrates smaller openings than the liquids used in dye penetrant inspection and fluorescent penetrant inspection.Krypton-85 is used to measure extruded film or coating weight during online production (table 1).

Table (1): Radioactive Properties of key Krypton Isotopes

Isotope	Half-life (y)	Specific Activity (Ci/g)	Decay Mode	Radiation Energy *(MeV)*		
				Alpha (α)	Beta (β)	Gamma (γ)
Kr-85	11	400	β	-	0.25	0.0022

Ci = curie, g = gram and MeV =million electron volts; a dash means the entry is not applicable.[14]

The instruments used for determination of the effective dose rate for the workers were:

1- AD6-6150 Automess Survey meter

This Survey meter is qualified to measure doses from gamma rays with measuring range 0.1 µSv/h – 10 mSv/h and Energy range 60 Kev-1.3 Mev . It is uncompensated GM tube.

2- Survey meter-Inspector EXP+

This Survey meter detects Alpha, Beta, Gamma and X-ray. It was designed for the requirements of emergency response personnel.It is uncompensated GM tube. The operating range: 0.01 µSv/h -1000 µSv/h.

3- Pocket Dosimeters

Direct Reading Pocket Dosimeters detected gamma radiation with exposure range (from 0 to 200mR), with effective dose range (from 0 to 2mSv) and energy range (from 160 keV to 2MeV).

4- Rad Pro Calculator Version 3.26:

Rad Pro Calculator performs many nuclear calculations that are useful to the health physicist, radiological researcher, radio chemist, radiation safety officer, health physics technician (HP) and nuclear medicine professional. It calculates, among other things, radiation safety unit conversions (SI and US customary) and gamma emitter dose rate and activity.

Operation Case:

The source which used in operating system is (Kr-85), gaseous, with dimension12, 7x13, 5 mm with initial activity 200mCi at 31/08/2010. Its activity at 15/07/2018 is 120.42mCi. [14, 15] The measurement points were explained in figure(3). The measurement locations were fifteen (15). These covered all places where the workers may expose to radiation during the operation. The nearest points to the source are (4) and (5) which are nearly in contact with the source. The experimental measurements were taken by using AD6-6150 Automess Survey meter and Survey meter-Inspector EXP+.

Krypton-85; is a medium energy beta source associated with gamma. It is suitable for measurements in the range of 150 to 1500 GSM (grams per square meter).

RERULTS AND DISCUSSION

The average measured doses at fifteen (15) points, around Extrusion Machine, monthly, (from 22/12/2010 to 26/06/2018) which explained in figure(3) are tabulated in the table(2). Hot spots have been determined in the working area to take the appropriate precaution to prevent and or decrease the radiation exposure to the workers. 15 points were selected in the working area where workers are founded during operation system as in figure (3)

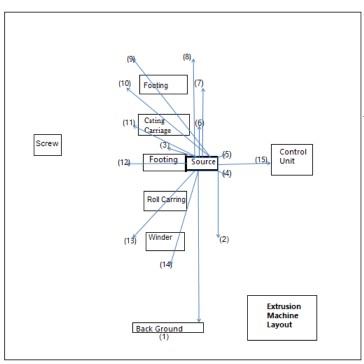

Figure (3): Extrusion Machine Layout

The average doses at different distance from Kr-85 source during 6 months have been measured and the data are represented in table (2). From this table it is clear that the maximum dose were 7.45 and 7.40 μSv/h at point's number 4 and 5 after 10 cm from the source.

Table (2): The dose rate measured at fifteen points at different distances with respect to Kr-85 source

Measuring points	Distance from Kr-85 source (m)	Average Dose rate during 6 months (uSv/h)
1	25	0.07
2	08	0.10
3	3.4	0.23
4*	0.1	7.45
5*	0.1	7.40
6	1.9	0.18
7	3.4	0.19
8	05	0.16
9	09	0.16
10	07	0.16
11	05	0.16
12	04	0.14
13	09	0.18
14	10	0.19
15	02	0.17

Table (2) explains the measured dose rate at (fifteen points) distances from Kr-85.

Table(3): The calculated doses at different distances from Kr-85 source (theoretically)

Distance (cm)	Dose Rate (μSv/h)
8	10.16
10	6.50
12	4.50
15	2.89
18	2.00
20	1.62
25	1.05
30	0.72
35	0.53
45	0.32
50	0.26
60	0.18
70	0.13
80	0.10
90	0.08
100	0.07

Table (3) explains the calculated doses at different distances from Kr-85 source theoretically by Rad Pro Calculator code

Version 3.26. When the distance to Kr-85 source increases the dose rate decreases. Figure (4) explained the relation between the distance from source and dose rate in the same location. The relation is explained by the exponential equation. It was inversely relation. At any distance (x) dose rate can be obtained that is when the distance increases, the dose decreases. Until at 50cm, the dose rate is nearly fixed. From this figure it is clear that effective dose decreases with increasing distance from the source. The doses vary from (10.16 μSv/h) at distance 8 cm to (0.07 μSv/h) at distance 1m. From table (3) and figure (4) we can conclude that the safe distance for the worker is 50 cm from the source.

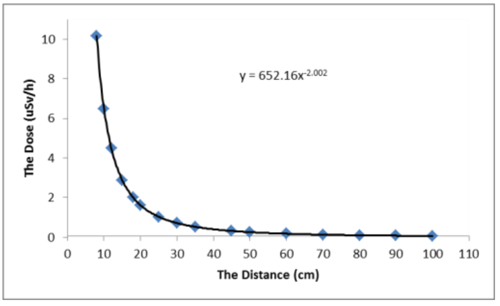

Figure (4): The calculated dose ratesby Rad Pro Calculator Version 3.26 fromKr-85 source (theoretically)

Comparison Study:

Comparison between AD6-6150 Automess Survey meter and Survey meter-Inspector EXP+ was done [the conversion factor from mR/h to μSv/h is nearly (10)) i.e. 1mR/h ≅ 10μSv/h)].The AD6-6150 measurements nearby to Inspector EXP+ measurements. This explained in table (4).

Table (4): comparison between measurements of two Survey meters (Experimentally).

Nor.	AD6-6150 Outomass Survey meter(µSv/h)	Survey meter-Inspector EXP+(mR/h)	Survey meter-Inspector EXP+(µSv/h)
1	0.08	0.007	0.07
2	0.12	0.01	0.1
3	0.33	0.023	0.23
4*	6.41	0.745	7.45
5*	7.4	0.740	7.4
6	0.19	0.018	0.18
7	0.11	0.019	0.19
8	0.15	0.016	0.16
9	0.15	0.016	0.16
10	0.15	0.016	0.16
11	0.15	0.016	0.16
12	0.16	0.014	0.14
13	0.15	0.018	0.18
14	0.14	0.019	0.19
15	0.19	0.017	0.17

Table (4): comparison between measurements of two Survey meters

Comparison between theoretical and experimental results:

The calculated doses at different distances from Kr-85 source (theoretically) were explained in figure(4) and Table(3). At distance (10cm) the dose rate was (6.5 µSv/h) theoretically. The average measured dose rate at the same distance (the nearest distance to the source) was (7.45-7.40 µSv/h).This means that the theoretical and measured readings are convergent. The measured effective dose rate was done by Direct Reading Pocket Dosimeters detected gamma radiation with exposure range (from 0 to 200mR), with effective dose range (from 0 to 2mSv) and energy range (from 160 keV to 2MeV). The readings were taken along one month. The average reading was (7.0 µSv/h)wich is nearby to the average measured dose rate at the same distance from two survey meters (7.45-7.40 µSv/h).

RISK FACTOR

Studies of workers in radiation-related occupations provide an opportunity to assess the health risks of low-dose ionizing radiation exposure. Various epidemiological studies of occupational exposure to ionizing radiation have been conducted in the form of national or international collaborative studies. [18].However, Melling, P.J.etal compared the possibility of finding risk in the process of casting away or emitting 85Kr from the different operations of reprocessing nuclear fuel to the operations that result from captivating and keeping ^{85}Kr. The average worker that was bared was estimated to receive 400 to 600 mrem/yr resulted from the activities of the absorption of decomposed organic matter by micro-organisms which also known as immobilization. This mentioned dose (0.02 mrem/yr) is a subset of 20000 to 30000 more than the estimated dose to the maximum individual, and is a subset of 130000 to 200000 more than that received by a member in a 50-mile populated set (0.003 mrem/yr). the different risk factors cannot be considered of meaning due to the uncertain or doubted factors in the models that increase the risk numbers, these include 0.02-0.027 radiation induced deadly cancers expected in the working numbers of individuals along with 0.017 deadly cancers in the overall population. There is no certain conclusion states that the risks resulted from the release of ^{85}Kr to the environment are greater than that resulted from the processes of immobilization, recovery or storage of the noble gas. [19]

CONCLUSION

Workers exposed to Kr-85 source with activity (200mCi) after (10 years) in working place to measure plastic thickness using in medical products, where the maximum exposure time is as a work day(i.e. 2000 h per year) the annual average dose for worker in the working place was 0 .01485 Sv i.e. in average (7.425uSv/h). This means that the working place is safe and the workers were also safe. The lifetime risk of cancer death is 4.1-4.8 % per man-Sievert (nearly 5%) for persons of working age (for adult only) i.e. 0.0891 man may die by cancer from this dose when workers exposed to Kr-85 source with activity (200mCi) after (10 years) (this value is neglected). This mean the working place is safe.

REFERENCES

(1) UW Health, School of medicine and public health, current as of, May 7,2017.
(2) ICRP 37, Cost-Benefit Analysis in the Optimization of Radiation Protection,1983.
(3) IAEA SAFETY STANDARDS SERIES No. GSR Part 3.
(4) ARPANSA Technical Report Series No. 131; Medical management of individuals involved in radiation accident (2000).
(5) Biological Effects of Ionization Radiation VII, UNSCEAR-1988(sources, effects and risks of ionizing radiation).
(6) UNSCEAR-2008, Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly with Scientific Annexes.
(7) ICRP-60,Recommendations of the International Commission on Radiological Protection, 1991..
(8) National Academy of Sciences Committee on the Biological Effects of Radiation, BEIR VII, Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. Washington, DC; National Academy of Sciences Press, 2006.
(9) How Beta Gauge Works – ATI Adaptive Technologies,www.atigauge.com/how-html/
(10) MANUAL ON NUCLEAR GAUGES IAEA, VIENNA, 1996 IAEA-PRSM-3 (Rev.1) IAEA, 1996.
(11) [http://www.radioactivity.eu.com/site/pages/Radioactive_Gauges.htm].

(12) Radiation Transmission-based Thickness Measurement Systems - Theory and Applications to Flat Rolled Strip Products Mark E. Zipf Tenova-I2S (I2S, LLC) United States of America, 01/04/2010.

(13) Jasch – Paper QCS (BTG 3000 PP), 2007.

(14) Human Health Fact Sheet ANL, October 2001.

(15) Certificate for Sealed Radioactive Source in used (Kr-85).

(16) ICRP Publication 103, The Recommendations of the International Commission on Radiological Protection, 2007.

(17) ICRP Statement on Tissue Reactions / Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context. ICRP Publication 118. Ann. ICRP 41(1/2), 2012.

(18) Lochbaum D., US Nuclear plants in the 21st century. The risk of a lifetime, Union of Concerned Scientists, May 2004. http://www.ucsusa.org/assets/documents/nuclear_power/nuclear04fnl.pdf

(19) Mellinger, P.J.; Brackenbush, L.W.; Tanner, J.E.; Gilbert, E.S. Krypton-85 health risk assessment for a nuclear fuel reprocessing plant, INIS, 6 (20),1985