ASSESSMENT OF INTERNAL CONTAMINATION WITH RADIOACTIVE IODINE FOR RADIATION WORKERS TWO-CASE STUDIES

N. E. Khaled
Department of Ionizing Radiation, National Institute for Standards, El-Haram, Giza, Egypt

ABSTRACT
For the purpose of occupational radiation protection against ionizing radiation, it is important to assess radiation risks due to any contamination events. Effective dose equivalent and body organs dose of workers exposed to ^{131}I have been estimated in this work. For this sake, both MONDAL 2.0 software and Visual Monte Carlo-dose calculation (VMC-dc) programs were applied. The cases under consideration are: 1) an overexposure of ^{131}I to ten radiation workers. This event happened during a maintenance period at a Korean nuclear power plant (NPP) where I-131 has been released to the reactor building from a primary system opening[1]. 2) The second event has been occurred in a chemical laboratory responsible for the production of radio-iodine ^{131}I. A release of the radioisotope in the laboratory air has lead to over exposure to one of the workers [2]. In both cases measurement of radiation activity took place with the use of different techniques where no measurements or estimation for organ doses were performed meanwhile.

Key words: *Mondal software, Visual Monte Carlo-dose Calculation (VMC-dc) and I-131.*

1. INTRODUCTION

The determination of internal doses is an essential component of individual monitoring programs for workers and members of the public, who may have intake of radionuclide following the release of radionuclide into the environment [3].

Internal contamination of workers may occur in nuclear industry due to intakes of radionuclides as a result of several activities. These include work associated with nuclear fuel cycle operations, the use of radioactive sources in medicine, scientific research, agriculture, industry, etc., [4]. Although, in any of these applications, best safety measures are implemented, possibility of release of radionuclides in working environment leading to intake by workers cannot be ruled out. The most common route of entry of a radioactive contamination into the body of a worker in the nuclear industry is by inhalation of airborne radioactivity. This may also occur through: (a) ingestion of food or water contaminated with radioactive materials, (b) injection by any sharp contaminated object penetrating the skin and/or (c) absorption through the intact skin is also possible but is less probable compared to entry through inhalation [5]. High dose of 131-I may result in abnormalities in body organs so it is important to estimate organ doses with good accuracy. Different kinds of tissues and organs have different sensitivities for radiation. Radiation doses in the various organs or tissues in the body cannot be measured directly, but can be assessed using organ dose calculation methodologies and various software’s [6].

1.1 MONDAL SOFTWARE

Mondal is a software developed by the National Institute of Radiological Sciences, Japan, intended for the estimation of internal doses based on retention or excretion measurements [7]. This software enables users to estimate intake of radionuclides inhaled or ingested by workers or by members of the public and resulting committed effective dose based on measurement results of individual monitoring. MONDAL contains the data set for the inhalation case. The calculation method is based on the methodology and parameters applied in ICRP publication No 78 [7], however the software also contains data for radonuclides, which were only in the relevant earlier publication of the ICRP No 54 [8], and data for several radionuclides, which are absent also from the new and old ICRP publications. Finally, the parameters applied in and the results calculated by the MONDAL software are consistent with the biokinetic data given in the ICRP pub.78, and with the dose factors of IBSS for both the inhalation and ingestion cases [9].

1.2 VISUAL MONTE-CARLO DOSE CALCULATION (VMC-dc) SOFTWARE

VMC-dc is a computer program that simulates the irradiation of the human body with photons. It uses a voxel simulator produced at Yale University and the Monte Carlo technique to simulate the emission of photons by a point, cloud or ground source. It then transports the photons through the human body simulator and calculates the dose to each body tissue or organ. VMC is designed specifically for voxel geometries and has an extensive graphic output. It is written in Visual Basic. As the energies of the radionuclides of interest for external dose calculations during most occupational exposure or accident situations fall in the range of 0.02-1.5 MeV, only photoelectric and Compton interactions were considered. The Monte Carlo code uses the RANMAR random number generator, with a period of approximately 10^30 random numbers. [10,11, 12].

2. MATERIALS AND METHODS

The selection of cases to be evaluated was taken on the basis of the radioisotope or mixture present in the case scenario. Generally the structure of the evaluation has the form:

• Brief description of cases.

• Reference software evaluation.

• Indication of best estimated value. For this sake:

1. The validation of Mondal software was made for internal contamination with I-131. The committed effective dose and activity of intakes, based on bioassay data was calculated for ten contaminated workers (case study-1) [1]. Also, the effective dose and activity of intakes for a worker subjected to overexposure of I-131 was performed (case study- 2)[2].
2. The program VMC-dc was then applied to the calculation of total dose received by each organ/tissue due to contamination with I-131 for all workers of the 2 mentioned case studies.

2.1 CASE 1: WHOLE BODY COUNTING FOR WORKERS INHALED I-131 DURING MAINTENNACE OF NPP

During a maintenance period at a Korean nuclear power plant, internal exposure of radiation workers occurred by the inhalation of 131-I released into the reactor building from a primary system opening. The internal radioactivity measurements of the radiation workers contaminated by 131-I were immediately conducted using a whole body counter and whole body counting was performed again a few days later. The intake calculated by hand, based on both the entrance records to radiation controlled areas and the measurement results of the air concentration for 131-I in these areas were compared with the results of whole body counting [1].

3. RESULTS AND DISCUSSIONS

3.1 RESULTS AND DISCUSSIONS of case 1

The two measured whole body activity of the ten korean workers are tabulated and used for calculation of effective dose to workers by mondal 2.0 software (table 1). The first measurement was immediately after the exposure and the recount was during the second week.

Table 1: the measured activity of intake and the calculated effective dose by Mondal software for the ten Korean workers.

Worker Code	Time (Day)	Activity of intake (Bq)	Effective Dose (Sv)	Time after recount (Days)	activty of intake after recount (Bq)	Effective Dose after recount (Sv)
1	2	2.90E+04	5.90E-04	13	2.50E+04	5.00E-04
2	1	3.10E+04	6.30E-04	10	2.40E+04	4.80E-04
3	1	8.10E+03	1.60E-04	12	2.70E+04	5.40E-04
4	1	3.70E+04	7.50E-04	13	5.30E+04	1.10E-03
5	1	2.50E+04	5.00E-04	12	2.60E+04	5.20E-04
6	1	1.50E+04	2.90E-04	11	2.10E+04	4.20E-04
7	1	1.70E+04	3.50E-04	12	2.60E+04	5.10E-04
8	1	4.00E+04	8.00E-04	12	2.60E+04	5.30E-04
9	1	1.70E+04	3.40E-04	13	6.70E+04	1.30E-03
10	1	4.70E+03	9.40E-05	9	8.00E+03	1.60E-04

From the above table, the calculated effective doses of the ten workers under investigation were varied from 0.42 to 1.3 mSv after activity recount. Figure 1 shows that more than five workers were still in the uptake region during the second recount. This can be attributed to the low biological half life of these workers in particular. Further measurements for those workers till approaching the attenuation region of the dose-time curve are requuired. The maximum effective dose was about 1.3 mSv for the 9th worker after 13 hours recount. The variation of the effective dose among workers may also attributed to the nature and circumstances of work of each person and his location at the laboratory.

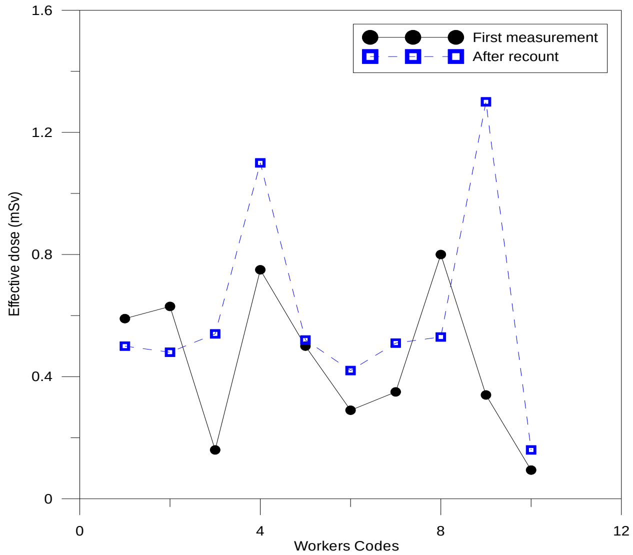

Figure 1: The effective dose in mSv for the ten workers calculated by Mondal software

Tables (2 to 11) show the results of VMC software calculations of the organ doses D(T) for the Korean workers for the first and second measurement each. The calculations were performed considering the inhaled activity with normal rate of retention and the radioactive isotope uptake would be at the thyroid gland.

Table 2: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the first contaminated worker with I-131 source.

Organ	Doses D(T) µGy (1^{st} meas.)	Doses D(T) µGy (2^{ed} meas.)
Gonads	0.00	0.01
Bone marrow	0.25	0.64
Colon	0.05	0.12
Lung	1.09	2.87
Stomach	0.15	0.4
Bladder	0.00	0.01
Liver	0.18	0.43
Oesophagus	5.57	13.4
Thyroid	218.84	574.79
Skin	0.1	0.25
Bone surface	0.4	1.05
Adrenals	0.07	0.26
Brain	0.09	0.23
Upper large int.	0.05	0.11
Small intestine	0.05	0.11
Kidney	0.11	0.26
Muscle	0.27	0.70
Pancreas	0.07	0.24
Spleen	0.18	0.47
Eye lens	0.10	0.14

Table 3: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the second contaminated worker with I-131 source.

Worker 2 Assume the activity concentrated in thyroid	Organ	Doses D(T) µGy (1^{st} meas.)	Doses D(T) µGy (2^{ed} meas.)
	Gonads	0	0
	Bone marrow	0.26	0.72
	Colon	0.04	0.13
	Lung	1.11	3.11
	Stomach	0.15	0.44
	Bladder	0.01	0.02
	Liver	0.17	0.48
	Oesophagus	5.18	14.59
	Thyroid	218.68	628.53
	Skin	0.1	0.27
	Bone surface	0.41	1.14
	Adrenals	0.06	1.01
	Brain	0.09	0.25
	Upper large int.	0.05	0.14
	Small intestine	0.05	0.14
	Kidney	0.10	0.28
	Muscle	0.27	0.76
	Pancreas	0.11	0.41
	Spleen	0.19	0.62
	Eye lens	0.30	0.39

Table 4: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the third contaminated worker with I-131 source.

Worker 3 Assume the activity concentrated in Thyroid	Organ	Doses D(T) µGy (1^{st} meas.)	Doses D(T) µGy (2^{ed} meas.)
	Gonads	0	0.00
	Bone marrow	0.01	0.74
	Colon	0	0.13
	Lung	0.06	3.28
	Stomach	0.01	0.46
	Bladder	0	0.01
	Liver	0.01	0.53
	Oesophagus	0.30	16.35
	Thyroid	12.35	653.18
	Skin	0.01	0.29
	Bone surface	0.02	1.19
	Adrenals	.01	0.56
	Brain	0	0.25
	Upper large int.	0	0.14
	Small intestine	0	0.14
	Kidney	0.01	0.31
	Muscle	0.02	0.79
	Pancreas	0.01	0.31
	Spleen	0.01	0.53
	Eye lens	0.02	0.26

Table 5: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the fourth contaminated worker with I-131 source.

Worker 4 Assume the activity concentrated in Thyroid	Organ	doses D(T) µGy(1st meas.)	doses D(T) µGy(2ed meas.)
	Gonads	0	0.01
	Bone marrow	0.12	1.37
	Colon	0.02	0.28
	Lung	0.51	6.02
	Stomach	0.07	0.78
	Bladder	0	0.04
	Liver	0.08	0.97
	Oesophagus	2.58	29.28
	Thyroid	101.51	1181.15
	Skin	0.04	0.55
	Bone surface	0.19	2.23
	Adrenals	0.02	0.64
	Brain	0.04	0.46
	Upper large int.	0.02	0.25
	Small intestine	0.02	0.25
	Kidney	0.04	0.51
	Muscle	0.12	1.47
	Pancreas	0.05	0.67
	Spleen	0.10	1.01
	Eye lens	0.04	0.16

Table 6: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the fifth contaminated worker with I-131 source.

Worker 5 Assume the activity concentrated in Thyroid	Organ	Doses D(T) µGy (1st meas.)	Doses D(T) µGy (2ed meas.)
	Gonads	0	0.01
	Bone marrow	0.24	0.73
	Colon	0.04	0.14
	Lung	1.06	3.25
	Stomach	0.14	0.43
	Bladder	0	0
	Liver	0.17	0.47
	Oesophagus	5.12	14.54
	Thyroid	211.14	631.41
	Skin	0.09	0.28
	Bone surface	0.39	1.18
	Adrenals	0.06	0.33
	Brain	0.09	0.25
	Upper large int.	0.04	0.11
	Small intestine	0.04	0.12
	Kidney	0.10	0.28
	Muscle	0.26	0.79
	Pancreas	0.07	0.42
	Spleen	0.17	0.55
	Eye lens	0	0.17

Table 7: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the sixth contaminated worker with I-131 source.

Worker 6	Organ	Doses D(T)µGy (1st meas.)	Doses D(T) µGy (2ed meas.)
Assume the activity concentrated in Thyroid	Gonads	0	0
	Bone marrow	0.03	0.58
	Colon	0.01	0.11
	Lung	0.12	2.61
	Stomach	0.02	0.38
	Bladder	0	0.03
	Liver	0.02	0.40
	Oesophagus	0.54	12.33
	Thyroid	23.31	508.82
	Skin	0.01	0.24
	Bone surface	0.04	0.96
	Adrenals	0.03	0.14
	Brain	0.01	0.22
	Upper large int.	0	0.11
	Small intestine	0.01	0.11
	Kidney	0.01	0.26
	Muscle	0.03	0.64
	Pancreas	0.02	0.26
	Spleen	0.02	0.46
	Eye lens	0.01	0.26

Table 8: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the seventh contaminated worker with I-131 source.

Worker 7	Organ	Doses D(T) Gy (1st meas.)	Doses D(T) µGy (2ed meas.)
Assume the activity concentrated in Thyroid	Gonads	0	0
	Bone marrow	0.16	0.72
	Colon	0.03	0.14
	Lung	0.74	3.15
	Stomach	0.11	0.46
	Bladder	0.01	0.01
	Liver	0.11	0.49
	Oesophagus	3.46	14.57
	Thyroid	146.69	639.12
	Skin	0.07	0.27
	Bone surface	0.27	1.15
	Adrenals	0.10	0.21
	Brain	0.06	0.26
	Upper large int.	0.03	0.14
	Small intestine	0.03	0.14
	Kidney	0.07	0.29
	Muscle	0.18	0.77
	Pancreas	0.09	0.33
	Spleen	0.12	0.62
	Eye lens	0.13	0.59

Table 9: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the eighth contaminated worker with I-131 source.

Worker 8 Assume the activity concentrated in thyroid	Organ	Doses D(T)µGy (1st meas.)	Doses D(T) µGy (2ed meas.)
	Gonads	0	0.01
	Bone marrow	0.31	0.71
	Colon	0.06	0.13
	Lung	1.38	3.16
	Stomach	0.19	0.44
	Bladder	.00	0.01
	Liver	0.23	0.48
	Oesophagus	7.02	14.81
	Thyroid	276.58	633.21
	Skin	0.12	0.28
	Bone surface	0.51	1.15
	Adrenals	0.08	0.28
	Brain	0.11	0.25
	Upper large int.	0.06	0.12
	Small intestine	0.06	0.12
	Kidney	0.14	0.28
	Muscle	0.34	0.77
	Pancreas	0.09	0.27
	Spleen	0.23	0.52
	Eye lens	0.12	0.16

Table 10: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the ninth contaminated worker with I-131 source.

Worker 9 Assume the activity concentrated in thyroid	Organ	Doses D(T) µGy (1st meas.)	Doses D(T)µGy (2ed meas.)
	Gonads	0	0
	Bone marrow	0.04	0.02
	Colon	0.01	00
	Lung	0.18	0.07
	Stomach	0.03	0.01
	Bladder	.00	.0
	Liver	0.03	0.01
	Oesophagus	0.85	0.33
	Thyroid	35.93	13.72
	Skin	0.02	0.01
	Bone surface	0.07	0.03
	Adrenals	0.02	00
	Brain	0.01	0.01
	Upper large int.	0.01	0
	Small intestine	0.01	0
	Kidney	0.02	0.01
	Muscle	0.04	0.02
	Pancreas	0.02	0.01
	Spleen	0.03	0.01
	Eye lens	0	0.02

Table 11: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the tenth contaminated worker with I-131 source.

Worker 10 Assume the activity concentrated in Thyroid	Organ	Doses D(T) µGy (1^{st} meas.)	Doses (T)µGy (2^{ed} meas.)
	Gonads	0	0.00
	Bone marrow	0.02	0.23
	Colon	.00	0.05
	Lung	0.07	0.99
	Stomach	0.01	0.14
	Bladder	.00	0.01
	Liver	0.01	0.16
	Oesophagus	0.34	4.80
	Thyroid	13.57	192.21
	Skin	0.01	0.09
	Bone surface	0.02	0.37
	Adrenals	0.00	0.06
	Brain	0.01	0.07
	Upper large int.	0.00	0.04
	Small intestine	0.00	0.04
	Kidney	0.01	0.08
	Muscle	0.02	0.24
	Pancreas	0.01	0.12
	Spleen	0.01	0.16
	Eye lens	.00	0.09

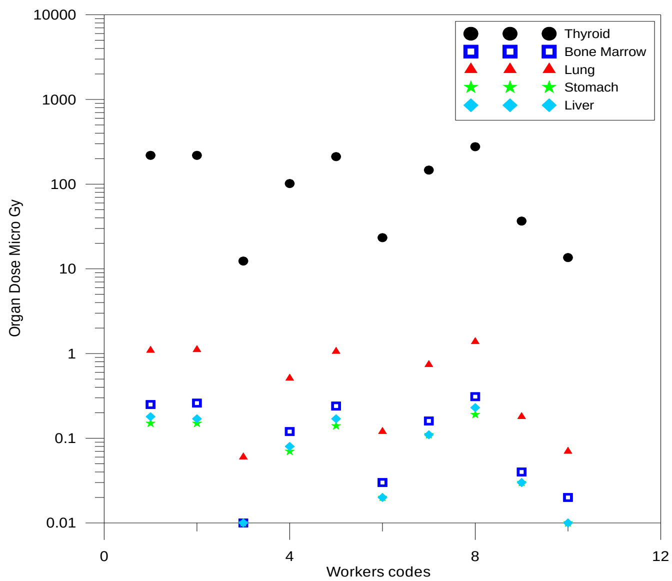

Figure 2: The organ dose in µGy for the ten workers calculated by the VMC for the first measurement after exposure.

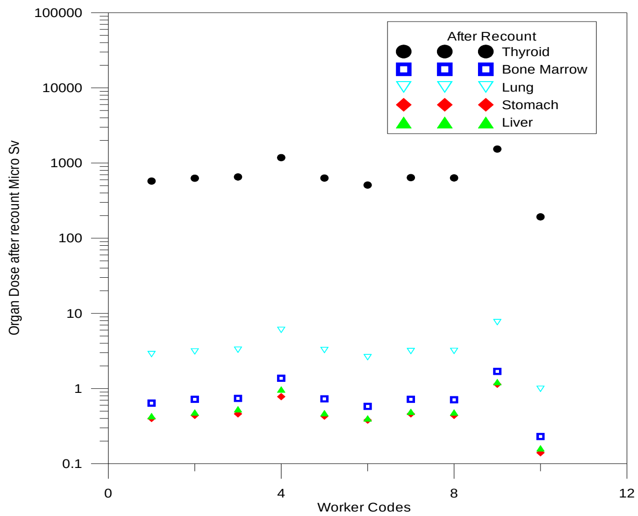

Figure 3: The organ dose in µGy for the ten workers calculated by the VMC for the second (recount) measurement after exposure.

Results of VMC calculations of Organ doses for the Korean workers based on the measured recount after several days of overexposure indicated the increase of organ doses, which can be attributed to the measurements which performed only twice, either during the build-up of I-131 uptake region or during the plateau ,but no pursuing measurements performed later to record the attenuation for all workers. VMC calculations showed that the maximum dose to eye lense was about 0.59 µGy for worker 7. While the maximum dose to Bone marrow was 1.37 µGy for worker 4, maximum dose to Gonads was about 0.02 µGy and the maximum Thyroid dose was 1.182 mGy. The maximum dose to lung 6.02 µGy, to stomach 0.78 µGy, and to liver 0.97 µGy. Results indicated that worker 4 received the maximum organ doses to almost all body organs, while no dose to gonads were registered for almost all workers.

CASE 2: INHALATION OF I-131 BY VITNAMESE WORKERS

During handling of highly radioactive material, I-131 a type of elementary iodine was released in the air of the laboratory which causes internal exposure to the radiation workers through inhalation. Therefore on the following days, the workers were routinely monitored via direct measurements (in-vivo) for thyroid as well as via indirect ones (in-vitro) by urine analysis, but the in-vivo method was used here. Because a high level of 131-I activity was measured in the thyroid, the measurement was repeated on the following days [2].

3.2 RESULTS AND DISCUSSIONS of case 2

Applying Mondal software to calculate the effective dose with the use of measured data performed to the worker who was subjected to I-131 contamination at chemical laboratory in Vietnam is presented in table 12.

Table 12: The measured activity of intake and the calculated effective dose by Mondal software for the Vietnam's worker over different time from exposure.

Time (days)	Activity of intake (Bq)	Effective dose(Sv)
1	9.00E+03	1.80E-04
2	8.60E+03	1.70E-04
3	8.60E+03	1.70E-04
5	8.60E+03	1.70E-04
7	8.60E+03	1.70E-04
9	8.60E+03	1.70E-04
10	7.80E+03	1.60E-04
12	7.10E+03	1.40E-04
15	7.80E+03	1.60E-04
17	8.10E+03	1.60E-04
20	5.90E+03	1.20E-04
25	6.00E+03	1.20E-04

From the above table, the maximum effective dose after one day of exposure was about 0.18 mSv and decayed to 0.12 mSv after the 25th day. On the other hand, applying the assumptions used in published data that 40 KBq acute intake of I-131 the effective dose calculated by Mondal would be 3.5 mSv, which is higher than the effective dose calculated by LUDEP 2.0 software which was 2.32 mSv. Applying the VMC software the different organ doses for the worker who was subjected to I 131 overexposure were calculated and presented in table (13) after different time from exposure.

Table 13: Organ/tissue dose calculation using VMC-dc for thyroid as source organ of the Vietnams' contaminated worker with I-131 source.

Organ	Doses D(T) µGy (1 day)	Doses D(T) µGy (3 days)	Doses D(T) µGy (7 days)	Doses D(T) µGy (10 days)	Doses D(T) µGy (15 days)	Doses D(T) µGy (25 days)
Gonads	0	0	0	0	0	.0
Bone marrow	0.05	0.12	0.21	0.19	0.18	0.09
Colon	0.01	0.02	0.04	0.04	0.04	0.02
Lung	0.22	0.55	0.90	0.88	0.82	0.40
Stomach	0.03	0.08	0.12	0.12	0.11	0.06
Bladder	0	0	0	0	0	0
Liver	0.04	0.09	0.13	0.13	0.13	0.06
Esophagus	1.09	2.66	4.08	4.30	4.13	1.94
Thyroid	43.57	108.42	176.53	175.28	161.87	81.01
Skin	0.02	0.05	0.08	0.08	0.08	0.04
Bone surface	0.08	0.2	0.33	0.31	0.30	0.15
Adrenals	0.04	0.03	0.08	0.07	0.14	0.11
Brain	0.02	0.05	0.07	0.04	0.06	0.03
Upper large int.	0.01	0.02	0.03	0.04	0.03	0.02
Small intestine	0.01	0.02	0.03	0.08	0.03	0.02
Kidney	0.02	0.05	0.08	0.21	0.07	0.04
Muscle	0.05	0.14	0.22	0.09	0.20	0.10
Pancreas	0.02	0.04	0.11	0.16	0.09	0.04
spleen	0.04	0.09	0.14	0.10	0.15	0.07
Eye lens	0.02	0.01	0.05	0.77	0.04	0

Results of VMC calculations shows that the worker's different organs have subjected to the following maximum doses: the Bone marrow with 0.21 µGy , eye lens with 0.77 µGy , thyroid with 176.53 µGy, the Stomach has received 0.12 µGy, and finally the Liver to 0.13 µGy.

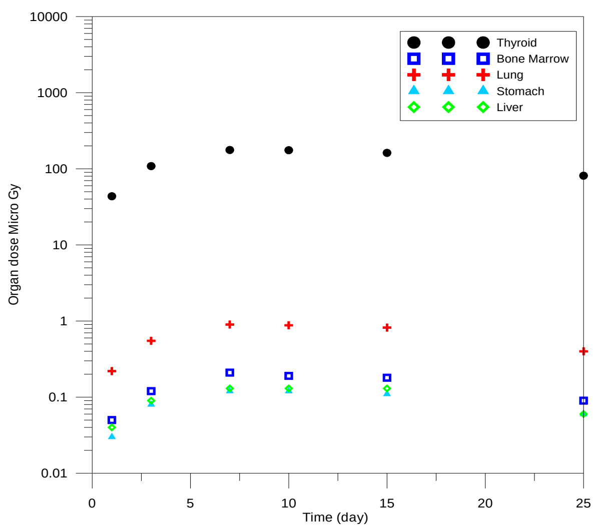

Figure 4: The organ doses calculated by VMC-dc for the Vietnam's worker with time

Figure 4 shows that: there is an increase in the organ dose gradually till the ninth day then a plateau region occurred. There is stability in organ doses till the attenuation starts at the 25th day. The small variations at the plateau may be attributed to the different sources of uncertainty during the detection process such as the background and instruments calibration at the site of the event.

4. CONCLUSION

For the purpose of occupational radiation protection against ionizing radiation, it is important to assess radiation risks due to any contamination events. In this work two case studies of occupational overexposure have been assessed. Mondal software implements the ICRP biokienetic models for estimation of intakes and effective doses. Mondal not only enable users to use the standard ICRP models but also to change any parameter value from ICRP defaults. It also facilitates the application of sophisticated data to internal dose calculations. The resulting effective dose are based on measurement results of individual monitoring of different types such as urine, faces and whole body monitoring.

The first case which occurred at a nuclear power plant and ten workers has been subjected to overexposure of I-131. The published data lacks of enough measurements for workers till the approach of decay which about 4 half-lives of the radioisotope. The second case of Vietnams' chemical laboratory, where a worker was subjected to I-131 over exposure and also no estimation of organ doses presented. In this study, this work tried to cover the missing parts of the published parts by calculating the total affective dose for different body organs for the contaminated workers.

Calculations using Visual Monte Carlo-dose calculations technique together with computational human models are very suitable method for the determination of organ and tissue doses from internal radiation exposure. It has also proved to be useful tool for fast evaluation of the radiation burden to contaminated workers in cases of suspected incidents.

5. REFERENCES

[1]. Tae Young, Hee Geun Kim. " A whole counting experience on the internal contamination of iodine 131 at a Korean nuclear power plant" . Progress in Nuclear science and Technology,vol.1,p. 174-177 (2011).

[2]. Nguyen Van Hung, Bui Van Loat." Intercomparison on internal dose assessment for 131 I " VNY journal of science ,Mathematics-physics 25,179-184, (2009).

[3]. Osamu Kurihara, Shinji Hato, Katsuta Kanai, Chie Takada, Koji Takasaki, Kimio Ito, Hiroshi Ikeda, Mikihiro Oeda, Naohiro Kurosawa, Kumiko Fukutsu, Yuji Yamada, Makoto Akashi and Takumaro Momose. "REIDAC-A Software Package for Retrospective Dose Assessment in Internal Contamination with Radionuclides". Journal of Nuclear Science and Technology, Vol. 44, No. 10, pp. 1337-1346 (2007).

[4]. Smith T, Petoussi-Heness N, Zankl M. "Comparison of Internal radiation Doses Estimated by MIRD and Voxel Techniques for a "family" of Photons". Journal of Nuclear Medicine, Vol. 46, No. 6, 1023-1027, 2005.

[5]. H. Doerfel, A. Andrasi, R. Cruz-Suarez, C. M. Castellani, C. Hurtgen, J. Marsh and J. Zeger. "IAEA/IDEAS Intercomparison Exercise on Internal Dose Assessment". Radiation Protection Dosimetry (2007), Vol. 125, No. 1-4, pp. 56-60.

[6]. N. Ishigure, "Electronic Look-up Tables on Retention and Excretion of Radionuclides as a PC based Support System for Internal Dosimetry". Radiation Protection Dosimetry, vol. 93, No. 2, pp 161-165 (2001).

[7]. ICRP; ICRP Publication 78, Ann. ICRP, 27(3/4), Elsevier Science Ltd., Oxford (1997).

[8]. ICRP; ICRP Publication 54, Ann. ICRP, 27(3/4), Elsevier Science Ltd., Oxford (1998).

[9]. IBSS; International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources. IAEA, Vienna, 1996.

[10]. S. A. Natouh, "Calculation of Radiation Dose from a Cloud of Radioactive Iodine using Voxel Phantoms and Monte Carlo Methods". World Congress on Medical Physics and Biomedical Engineering, Sep. 7-12, 2009, Munich, Germany.

[11]. J. G. Hunt, F. C. A. da Silva, C. L. P. Mauricio and D. S. dos Santos "The Validation of Organ Dose Calculations using Voxel Phantoms and Monte Carlo Methods Applied to Point and Water Immersion Sources" radiation Protection Dosimetry, Vol. 108, issue 1, pp. 85-89, 2004.

[12]. M.R. Ay1∗, M. Shahriari, S. Sarkar, P. Ghafarian **"**Measurement of organ dose in abdomen-pelvis CT exam as a function of mA, KV and scanner type by Monte Carlo method" Iran. J. Radiat. Res., 2004; 1(4): 187-194.