JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]

Revision of red bone marrow doses of Chernobyl clean-up workers based on conversion coefficients from advanced phantoms depending on the body weight

K. Chizhov and C. Lee

Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institute of Health, Rockville, MD 20850, USA

NATIONAL CANCER INSTITUTE

INTRODUCTION

After the accident on Chernobyl nuclear power plant (ChNPP) on April 26 1986 several hundred thousand workers, called "liquidators" or "clean-up workers" took part in decontamination and recovery activities. The Chernobyl liquidators were mainly exposed to external ionizing radiation levels that depended primarily on their work locations and the time after the accident when the work was performed. Individual doses were often monitored inadequately or were not monitored at all for the majority of liquidators, therefore a method of photon (i.e., gamma and x rays) dose assessment, called "RADRUE" (Realistic Analytical Dose Reconstruction with Uncertainty Estimation) [1], was developed to obtain unbiased and reasonably accurate estimates for use in epidemiologic studies. RADRUE was used for assessment of the red bone marrow (RBM) doses in the study of leukemia risk among liquidators [2].

In RADRUE conversion coefficients (CC) for organ doses were selected on the basis of available measurements for locations inside Unit 4 of ChNPP, documentation from ICRP [3], and expert judgment. The conversion coefficients were obtained as the products of the conversion coefficients from air kerma rate to organ dose rate and from exposure rate to air kerma rate. The organ dose rates per air kerma rates vary according to the geometry of exposure and the energy spectra of the photons that characterize the radiation fields, whereas the ratio of air kerma rate to exposure rate is a constant equal to 8.7 10^{-3} mGy h^{-1} per mR h^{-1}. Irradiation geometries varied with location and were in many cases a mixture of anterior-posterior (AP), rotational (ROT), and isotropic (ISO) geometries.

RADRUE takes into account uncertainties in exposure-rate data and soil-contamination measurements, in the interpolation of these data in time and space, uncertainties in factors used to characterize the effectiveness of shielding, and imprecision of data from the questionnaire. RADRUE also considers mistakes in questionnaires (human factor uncertainties). But the uncertainty in RADRUE does not take into account weight of liquidators, which impacts on the RBM dose [4]. Also, ICRP Publication 116 [5] coefficients were calculated on a new more precise phantoms and they differ from previous ones. Therefore, distribution of CC used in RADRUE not overlap the all possible types of irradiation.

Aim of the study

The current study was intended to evaluate the impact of body weight of the workers on red bone marrow dose.

MATERIALS & METHODS

The cohort consisted of 137 cases of leukemia with 863 workers in control group. Air kerma for each individual was extracted from the RADRUE dosimetry database.

The RADRUE implements a time-and-motion dose reconstruction method. Based on detailed questionnaires of liquidators it assess the air kerma dose. RBM dose for each liquidator was calculated using CCs from ICRP Publication 74 [3] and air kerma by means of 10,000 stochastic simulations. In RADRUE calculation the CC was presented as normal distribution, the mean value and standard deviation was used for certain energies and irradiation types.

In this study the RBM dose was calculated using air kerma dose from RADRUE and CCs from the body size dependent hybrid phantoms [4]. CCs from the original CCs from the recent CCs based on realistic computational human phantoms from ICRP Publication 116 were compared with the ICRP Publication 74 phantoms and body size-dependent CCs [5].

RESULTS

In RADRUE for red bone marrow dose reconstruction the calculation was carried out by means of 10,000 stochastic simulations of the conversion coefficient. The conversion coefficient was presented as normal distribution, the mean value and standard deviation was used for certain energies and irradiation types (for roofs mean=0.72 σ=0.07; for other locations mean=0.77, σ=0.08).

RADRUE takes into account uncertainties in exposure-rate data and soil-contamination measurements, in the interpolation of these data in time and space, uncertainties in factors used to characterize the effectiveness of shielding, and imprecision of data from the questionnaire. RADRUE also considers mistakes in questionnaires (human factor uncertainties) [6].

But the uncertainty in RADRUE does not take into account weight of liquidators, which impacts on the RBM dose [4]. The calculation results are also affected by the phantom model. ICRP Publication 116 coefficients were calculated on a new, more precise phantoms and they differ from previous ones. Therefore, distribution of CC used in RADRUE not overlap the all possible types of irradiation and were corrected in this study.

In this work RBM dose were recalculated with distributions of conversion coefficients based on Lee's data [4]. The impact to the RBM dose of the weight of liquidator was assessed.

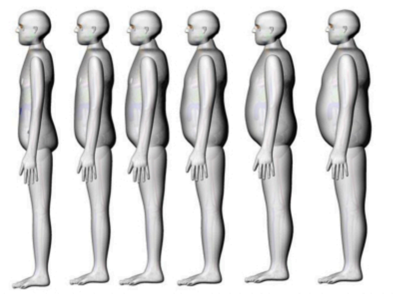

Figure 1. Body-weight dependent phantoms for weight 60-110 Kg.

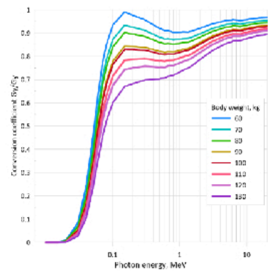

Figure 2. Dependence of the conversion coefficient on body weight for the AP exposure situation.

Table 1. Conversion coefficients for red bone marrow

Source of data	RBM, AP, E = 0.15 - 0.4 MeV	RBM, Mixture of AP, ROT and ISO, E = 0.15 - 0.4 MeV
ICRP74 [3]	0.755 – 0.808	0.665 – 0.866
ICRP116 [5], male phantom	0.888 – 1.060	0.467 – 1.060
Lee [4], male phantom, 60 Kg	0.936 – 0.990	0.681 – 0.990
Lee [4], male phantom, 110 Kg	0.783 – 0.790	0.574 – 0.788

The CC for RBM were obtained as the products of the conversion coefficients from air kerma rate to organ dose rate (mGy h^{-1} per mGy h^{-1}), Table 1.

RBM dose for clean-up workers cohort was calculated in six scenarios of different irradiation type and weight (Table 2). In RADRUE database is no information on weight of liquidators. RBM dose calculated in RADRUE using ICRP74 [3] CCs is presented on 7^{th} row in Table 2. Based on the anthropometric data [7] range from 60 to 110 kg for the weight of liquidator was selected.

For most operations with radioactive sources, anterior-posterior (AP) geometry is used. Since we did not have information about the type of exposure for liquidator in each situation, a mixture of AP, rotational (ROT) and isotropic (ISO) exposure situations was also considered as irradiation scenario.

CC for RBM for different weight and energy were calculated by C. Lee [4]. For each scenario CCs were presented as a normal distribution, with mean and standard deviation for selected CC values. Results for 10000 Monte-Carlo simulations for each scenario are presented in Table 2.

Table 2. Red bone marrow dose for ChNPP clean-up workers cohort

Case	Exposure geometry	Body weight, kg	Mean RBM dose, mGy	Median RBM dose, mGy	RBM dose range, mGy	σ, mGy
1	AP	60-110	140	21	4.4e-05 - 3890	362
2	AP	60	157	23	4.9e-05 - 4337	404
3	AP	110	127	19	3.9e-05 - 3492	326
4	mixture of AP, ROT and ISO	60-110	124	18	3.9e-05 - 3429	319
5	mixture of AP, ROT and ISO	60	137	20	4.3e-05 - 3765	351
6	mixture of AP, ROT and ISO	110	112	17	3.5e-05 - 3115	290
7	RADRUE	-	118	17	3.5e-05 - 3255	304

Table 2 shows that body weight affects the RBM dose. For the same irradiation situation for workers with body mass 110 kg the mean RBM dose is 20% lower than for 60 kg. For the AP irradiation geometry for 60 Kg body weight the mean dose is 16% higher that the mean dose in RADRUE, therefore for this kind of worker an underestimation of the RBM dose is possible.

CONCLUSIONS

1. For the same irradiation situation for workers with body mass 110 kg the mean red bone marrow dose is 20% lower than for 60 kg. For the AP irradiation geometry for 60 kg body weight the mean dose is 16% higher than the mean dose in RADRUE, therefore for this kind of worker an underestimation of the RBM dose is possible.
2. The difference in conversion coefficients for red bone marrow will be significant while reducing other uncertainties of the RADRUE method.
3. The mean red bone marrow dose for the selected cohort with the body size-dependent conversion coefficients coincide with the RARRUE results within the uncertainty.

REFERENCES

1. Kryuchkov V et al Radrue method for reconstruction of external photon doses to Chernobyl liquidators in epidemiological studies. Health physics. 2009 Oct;97(4):275.
2. Chumak V Dosimetry support of the Ukrainian-American case-control study of leukemia and related disorders among Chornobyl cleanup workers. Health physics. 2015 Oct;109(4):296.
3. ICRP, International Commission on Radiological Protection, International Commission on Radiation Units. ICRP Publication 74: Conversion Coefficients for Use in Radiological Protection Against External Radiation. Elsevier Health Sciences; 1996.
4. Lee C. et al Body size–specific organ and effective doses of chest CT screening examinations of the national lung screening trial. American Journal of Roentgenology. 2017 May;208(5):1082-8.
5. ICRP, Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures, International Commission on Radiological Protection (ICRP) Publication 116, Elsevier, 2010.
6. Chumak V. et al Dosimetry support of the Ukrainian-American case-control study of leukemia and related disorders among Chornobyl cleanup workers. Health physics. 2015 Oct;109(4):296.
7. Brainerd E. Reassessing the standard of living in the Soviet Union: An analysis using archival and anthropometric data. The Journal of Economic History. 2010 Mar;70(1):83-117.

DISCUSSION

The organ dose conversion coefficients for the male and female phantoms show their largest differences at photon energies from 40 to 80 KeV [5]. For the ChNPP accident it doesn't play a significant role. The photon energy spectra on the area contaminated with radionuclides varied from one location to another and from one time period to another, but were generally centered between 0.15 and 0.4 MeV [1].

In RADRUE the ROT geometry was considered to be the most representative for working conditions on the roofs, while mixtures of AP, ROT, and ISO geometries were used for all other areas [1]. In RADRUE calculations RBM CC was presented as a Normal distribution with mean = 0.72, σ = 0.07 for all areas except roofs of the 4^{th} Block of ChNPP. On roofs of 4^{th} Block of ChNPP CC was presented as a Normal distribution with mean = 0.77, σ = 0.08.

Calculations of the CCs on more detailed phantoms (Table 2) showed that the underestimation or overestimation of the RBM dose is possible.

In retrospective dose assessment for ChNPP cohort the dose range is 8 orders of magnitude. The highest doses were estimated for individuals who started their work on 26 April 1986 (the day of the accident). The lowest dose was received by a person who briefly passed the contaminated area onboard the radiation reconnaissance airplane. With such large uncertainties, the contribution from body weight may not be significant and do not change the type of dose distribution in the cohort. However, for a dose reconstruction and related risks of diseases of a particular person the body weight could help to clarify the dose up to 20%. CCs play a role of a scale factors, and scale changes may lead to changes in risk ratios.

Leukemia is one of the cancers most susceptible to induction by ionizing radiation, specified RBM dose assessment will help in the analysis of the risk of this disease.

ACKNOWLEDGEMENTS

This work was supported by the intramural research program of the National Institutes of Health, National Cancer Institute, Division of Cancer Epidemiology and Genetics.

CONTACT INFORMATION

Konstantin Chizhov, PhD,

Postdoctoral fellow.

National Cancer Institute,
Division of Cancer Epidemiology and Genetics,
Radiation Epidemiology Branch.
NCI Shady Grove, 9609 Medical Center Drive, Rockville, MD 20850.

Konstantin.Chizhov@nih.gov

https://dceg.cancer.gov