CO10-1 Assessment of non-homogenous exposure of radiation workers in an accelerator facility – situation in the small linac facility -

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INTRODUCTION: The annual dose limit of the lens of the eye for occupationally exposed personnel has been declined down to o 20 mSv averaged over five consecutive years and 50 mSv in any single year followed by the International Atomic Energy Agency [1], the European Union [2] and the United States [3].

The purpose of the study is to clarify the situations where inhomogeneous exposure is taken place for radiation workers engaged in the accelerator facility and to assess whether the additional monitoring of the eye lens dose should be performed for the workers. The authors introduce a quantitative index, homogenous index (HI), which is defined as the ratio of the personal dose equivalent for the eye lens and the extremity monitoring to that for the whole-body monitoring. The HIs were then experimentally estimated using the physical and mathematical phantoms for specific works accompanying inhomogeneous exposure to radiation from activated materials.

EXPERIMENTS: The authors focused on the exposure situation of radiation workers who are engaged in the handling of the activated target in the linac facility. As shown in the Figure 1, the physical phantom was placed in the workplace to mimic the respective work. The Optically Stimulated Luminescence (OSL) dosimeters (nanoDot^{TM}, Nagase Landauer Ltd.) were put on the water-filled phantom. The OSL dosimeters were put on the fingers and palms of the physical phantom as well as positions of eye lens, neck and chest. The ambient dose equivalent rate at the distance of 1 m from the target was measured to be 600 μSv h^{-1}. The physical phantom with the OSL dosimeters was set for 2 hours and the OSL dosimeters were read after the irradiation. The Monte Carlo calculations were carried out to estimate the HIs in the actual situations, introducing the PHITS 3.06 and the mathematical phantom.

Figure 1 Experimental setup for mimicing the actual radiation work engaged in the linac facility

RESULTS: Comparison of the ratio of the eye lens dose or the extremity dose to the trunk dose measured on the physical phantom and calculated by Monte Carlo calculation is listed in the Table 1. To simulate the Ta target handling, the physical phantom was set close to the target and put the palm onto Ta target directly, As shown in the table 1, the theoretically estimated HIs can predict the measured HIs accurately. As for extremity, the discrepancy between analytically estimated and measured HIs were found to be more than factor 2. On the other hand, calculated HIs reproduce the measured HIs within uncertainties. This would be explained by the main source of exposure is gamma rays from ^{182}Ta and well simulated geometry.

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Table 1 Evaluated HIs from measurement using the physical phantom and the OSLs in the exposure situation which the adjustment of the target is simulated

	Experimentally obtained HI^{eye} or HI^{ext}	Ratio analytically estimated from the inverse square law	HI^{eye} or HI^{ext} estimated by Monte Carlo calculations
Right eye lens dose vs Trunk dose $H_p(3)_{eye}$ / $H_p(10)_{trunk}$	0.42 ± 0.02	0.39	0.38 ± 0.06
Left eye lens dose vs Trunk dose $H_p(3)_{eye}$ / $H_p(10)_{trunk}$	0.37 ± 0.02	0.39	0.38 ± 0.06
Right finger dose vs Trunk dose $H_p(0.07)_{ext}$ / $H_p(10)_{trunk}$	33.5 ± 0.7	63.1	35.9 ± 2.3
Left finger dose vs Trunk dose $H_p(0.07)_{ext}$ / $H_p(10)_{trunk}$	1.84 ± 0.04	5.15	1.40 ± 0.11

CO10-2 Effective Measures on Safety, Security, Hygiene and Disaster Prevention in Laboratories

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INTRODUCTION: Important aspects of the study can be found in the following keywords, such as safety, security, hygiene and disaster prevention. Nuclear research reactor is one of representative facilities together with these keywords under their operation. It is effective to investigate the latest status on practical measures on these keywords in various facilities including nuclear research reactors, to compare each other among facilities, and to discuss more optimized ones for our positive safety management. Through this process, it is also essential to investigate the latest international and/or national regulations and the movement of revision of them. In addition, development of human resource and public literacy on nuclear science and technology is also within the scope of the research. The total discussion contents and their fruits are directly useful for all relating laboratories.

RESEARCH APPROACH:
General research approach is as follows.
- Measures of safety management during operation or standstill status of the real facilities would be investigated. This information would be used for our research discussion on the positive and more optimized safety management.
- It would not be a single year research, but maybe two to three years research for one theme.
- Information source of facilities would not be only KUR, KUCA or the other facilities in Kyoto University, but also the Kinki university research nuclear reactor or the facility of National Institute of Fusion Science, etc. This research is an active joint-research with these relating facilities and positive researchers on safety management.
- One of the distinctive features of this research is to involve office staffs as cooperators as well as researchers and technical staffs. In The University of Tokyo, most of the members in Division for Environment, Health and Safety are office staffs who knows real situation of safety management in laboratories very well.

Concrete discussion target in FY of 2020 was determined as following two; “developing a set of educational videos for safety managers and workers in universities on application of small amount of U and Th” and “opinion survey on radiation safety culture activity” through our member discussion.

DEVELOPING EDUCATIONAL VIDEOS IN UNIV. FOR SMALL AMOUNT U & Th APPLICATION:
Safety education system for managers and users of small amounts of U and Th had been discussed to standardize it in universities by the FY 2019. The discussion fruits were published in the early 2020 as the reference [1]. Based on the results, we developed a set of new safety educational videos, which is 5-10 min for each; (1) Domestic and international situation regarding nuclear material management (2) Basics of radiation (3) Radiation exposure and its human body effects (4) Properties of nuclear material and precautions for handling (5) State System of Accounting for and Control: SSAC (6) Trouble cases related to K-facility (7) Points to keep in mind for workers in research reactors, etc. These videos will be opened and used from FY 2021 in The University of Tokyo.

OPINION SURVEY ON RADIATION SAFETY CULTURE ACTIVITY:
We conducted questionnaires on safety culture mainly to radiation safety managers at radiation facilities. This has two objectives: (a) Extracting keywords for fostering a safety culture at radiation facilities mainly for radiation safety managers; (b) Organize and analyze trends in opinions of radiation safety managers and radiation workers. A deeper level of information is needed for Objective (a). Therefore, an open-ended questionnaire was adopted. Objective (b) requires a lot of data to analyze it. For this reason, a selective questionnaire was adopted. The questionnaire showed trends based mainly on differences in the size and purpose of radiation facilities. There was a big difference in the tendency to recognize "accidents, incidents, troubles and failure cases" between small- and large-scale facilities. Many respondents from large-scale facilities answered that they could easily share the latest related information in their facilities. This is probably because large-scale facilities usually have existing systems and chances to share information relating accidents in contrast to small-scale facilities. A part of the discussion fruits is presented in International Conference on Radiation Safety: Improving Radiation Protection in Practice hosted by IAEA Headquarters, held in Dec. 2020. We continue the analysis of the questionnaire responds.

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CO10-3 Mass balance trend of organochlorine and organobromine in a sediment core from Beppu Bay

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INTRODUCTION: Among organochlorine and bromine compounds, persistent organic pollutants (POPs) are subject to international regulation of production and use and reduction of unintentional generation under the Stockholm Convention because they are persistent, highly accumulative, and long-lasting. The number of compounds registered as POPs is increasing, and some of the alternatives have been reported to have the same properties as POPs. Therefore, a comprehensive evaluation is needed. POPs released into the environment are known to be distributed in sediment [1].

Therefore, the purpose of this study was to evaluate the potential pollution in the environment using sediment samples from Beppu Bay. The concentration change of the fraction of extractable organohalogens (EOX : X = Cl, Br) with a molecular weight of 1000 g/mol or less (EOX-L) in the sediment was compared with the concentration changes of individual substances (Polychlorinated Biphenyls (PCBs), Polybrominated diphenyl ethers (PBDEs) and Decabromo diphenyl ethane (DBDPE)).

EXPERIMENTS: The samples were collected from Beppu Bay, where well-preserved sediment cores are available. 2 g of freeze-dried sample was Soxhlet extracted with toluene and the extract was replaced with hexane. Inorganic chlorine and bromine were washed out, and then fractionation was carried out using gel permeation column chromatography based on a molecular weight of 1000 g/mol. Each extract was concentrated to 1-2 mL, and it was diluted to 5mL with hexane. 2 mL of diluted extract was nitrogen-concentrated to 1 mL and placed in a polyethylene (PE) bag along with filter paper. The mixture was dried under normal temperature and pressure until the liquid components were completely volatilized, and then sealed with a sealer. The samples were folded into 1.5 cm squares, placed in PE bags, double sealed with PE bags, and finally sealed in thin PE bags. Samples were irradiated for 15 min with a thermal neutron flux of $2.0–2.4\times10^{13}$ $cm^{-2}\cdot S^{-1}$ at KURNS. ^{38}Cl ($t_{1/2}$ = 37.18 min, E_γ = 1642, 2168 keV) and ^{80}Br ($t_{1/2}$ = 17.6 min, Eγ = 616 keV) were measured by using a Ge semiconductor detector for 60 sec. In the same way, samples of PE bag only, filter paper and PE bag only were also prepared and measured. The concentration of halogens in the sediment samples was determined by excluding the amount of halogens from the PE bags and filter papers.

RESULTS: The experimental results for chlorine and bromine are shown in Figure1, and the concentration of PCBs, PBDEs and DBDPE were reported in the previous reports [2,3]. The amount of chlorine in the samples was found to exist in the ratio of sediment-derived: PE bag-derived: filter paper-derived = 1.0: 1.6: 5.4. Due to the high amount of non sediment-derived chlorine, the calculation of some samples resulted in negative values. In Fig.1(A), The concentrations of EOCl-L and PCBs both increased around 1970, but since 1980, PCBs concentrations have been decreasing while EOCl-L concentrations have been increasing, indicating different trends. In Figure1(B), EOBr, PBDEs, and DBDPE increased from 1980 to 1995, but PBDEs have been decreasing since 1995, while EOBr-L and DBDPE have been increasing.

Although there is a large difference in the concentrations of EOX and individual substances, the timing of the increase in EOCl-L and PCBs around 1970 and the increase in EOBr-L, PBDEs, and DBDPE around 1980 coincides with each other, suggesting that changes in the concentrations of POPs and other substances have some effect on EOX-L. Therefore, EOX-L can be used as an indicator for monitoring the contamination status of POPs and other POPs-like substances. In the future, it is necessary to improve the sample preparation method of chlorine in neutron activation analysis and to investigate the sediment in other areas.

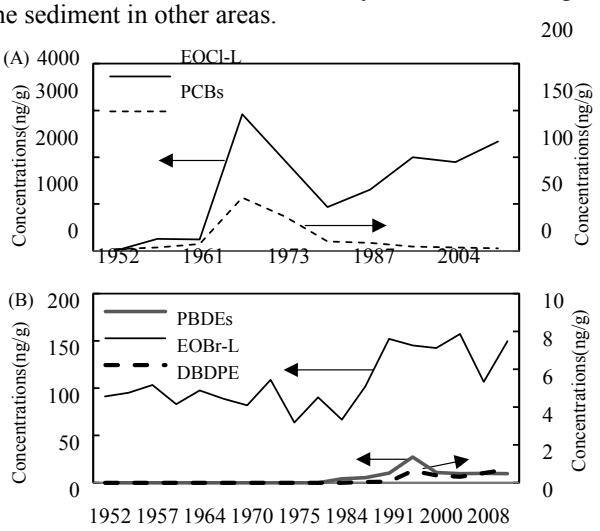

Fig. 1. (A) Concentrations of EOCl-L and PCBs. (B) Concentrations of EOBr-L, PBDEs and DBDPE.

ACKNOWLEDGEMENT:
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CO10-4 Application of KURAMA-II to Radiation Monitoring of Public Facilities in Fukushima Prefecture

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INTRODUCTION: KURAMA (Kyoto University RAdiation MApping system)-II is a radiation measurement system characterized by its compactness, autonomous operation, and acquisition of pulse-height spectrum data [1]. KURAMA-II measures ambient dose equivalent rate $H^*(10)$ (hereafter referred to as air dose rate) and GPS position and automatically transmits them to a dedicated cloud server. Air dose rate maps and pulse-height spectra are easily checked by accessing the server via the Internet (Figs. 1 and 2). We used the system in a backpack style (Fig. 3) and evaluated its effectiveness for radiation monitoring of public facilities in Fukushima prefecture.
EXPERIMENTS: The air dose rates of five public facilities were measured by walking with a KURAMA-II in a backpack. The situation of the sites are as follows.

Fig. 1. A typical example of air dose rate maps obtained by KURAMA-II measurement.

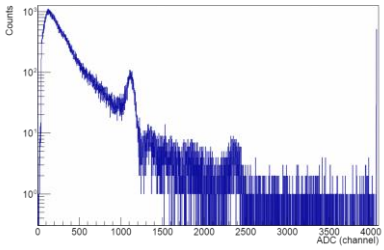

Fig. 2. A typical example of pulse-height spectra obtained by KURAMA-II measurement.

Fig. 3. KURAMA-II in a backpack.

Site A: School grounds and surrounding road
Site B: Gymnasium grounds and surrounding road
Site C: Community center grounds and surrounding road
Site D: School grounds and surrounding road
Site E: Park in forest

A CsI(Tl) scintillation detector (C12137-01, Hamamatsu Photonics) was used for measurement. The air dose rate and GPS position were measured every 3 seconds. The same route was also measured by walking with a GAMMA-plotter H (Japan Radiation Engineering) to examine the dependences of the result towards the walk survey systems. Air dose rates at 10-14 points in each site were measured by a NaI(Tl) scintillation survey meter (TCS-172B, Hitachi) for validity confirmation.
RESULTS: Air dose rates measured by KURAMA-II and GAMMA-plotter H were basically the same at all measurement sites (Fig. 4), and they were well consistent with the results from the survey meter.
Additionally, the air dose rate owing to artificial radionuclide were separately evaluated using pulse-height spectrum data by KURAMA-II, referring to previous report [2]. As shown in Table 1, the mean air dose rates owing to artificial radionuclides were 0.035-0.102 μSv/h and the ratio towards the total air dose rate was 0.43-0.67.
In conclusion, KURAMA-II showed the sufficient performance for monitoring of public facilities.

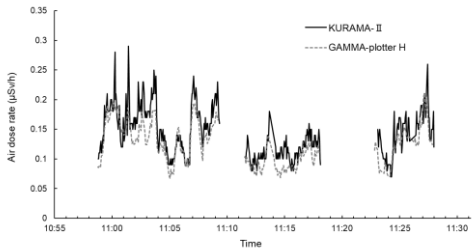

Fig. 4. A typical result of air dose rates measured by KURAMA-II and GAMMA-plotter H.

Table 1. The air dose rate owing to artificial radionuclide evaluated by KURAMA-II. The values are averaged for each measurement site.

Site	Mean air dose rate (μSv/h)		Ratio (Artificial/Total)
	Total	Artificial	
A	0.099	0.062	0.62
B	0.114	0.063	0.55
C	0.083	0.035	0.43
D	0.140	0.090	0.64
E	0.153	0.102	0.67

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R2095

CO10-5 Theoretical Study on Soil Adsorption/Desorption Characteristics of Cs and Sr Using PHREEQC

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INTRODUCTION: To remediate the contamination by radioactive Cs and Sr caused by an atomic power plant accident, it is necessary to elucidate their elution mechanism in soil. This study tries to estimate elution quantity of Cs and Sr considering competitive sorption by other cations using PHREEQC which is a free and versatile geochemical code.

THEORY AND EXPERIMENTS: Ca^{2+}, K^+, Mg^{2+}, and NH_4^+ are considered as cations which can adsorb to RES (Regular ion Exchange Site) and can be competitive with Sr^{2+} adsorption. K^+ and NH_4^+ are considered as cations which can adsorb to FES (Frayed Edge Site which has high adsorption-selectivity of Cs) and can be competitive with Cs^+ adsorption. These cations adsorption to each site was analyzed by PHREEQC with the surface complex model.

For modelling the adsorption site in PHREEQC, adsorption reaction formula and equilibrium constants are necessary to be defined. The equilibrium constants regarding RES were defined as follows:

$$K_{r-Sr} = [SrXr^+]/([Sr^{2+}][Xr^-]) \quad (1)$$
$$K_{r-Ca} = [CaXr^+]/([Ca^{2+}][Xr^-]) \quad (2)$$
$$K_{r-K} = [KXr]/([K^+][Xr^-]) \quad (3)$$
$$K_{r-Mg} = [MgXr^+]/([Mg^{2+}][Xr^-]) \quad (4)$$
$$K_{r-NH4} = [NH_4Xr]/([NH_4^+][Xr^-]) \quad (5)$$

Where,
K_{r-M} : equilibrium constant of cation M to RES (L/meq),
$[MXr]$: adsorption quantity of cation M(meq/100g-soil),
$[M^+]$: concentration of cation M in the solution(meq/L),
$[Xr^-]$: quantity of free site of RES(meq/100g-soil).
All cations are considered exchangeable and quantity of RES is considered to be same as that of CEC (Cation Exchange Capacity), and so, sum of cations existed in the solution and cations adsorbed on RES is considered as the quantity of exchangeable cations. Based on these assumptions, each equilibrium constant regarding RES can be estimated by measurement of CEC of the soil, quantity of each exchangeable ion, and concentration of each cation in the solution, and then, adsorption site of RES can be numerically defined in PHREEQC.

Adsorption reactions to FES are defined as follows:

$$K_{f-Cs} = [CsXf]/([Cs^+][Xf^-]) \quad (6)$$
$$K_{f-K} = [KXf]/([K^+][Xf^-]) \quad (7)$$
$$K_{f-NH4} = [NH_4Xf]/([NH_4^+][Xf^-]) \quad (8)$$

Where,
K_{f-M} : equilibrium constant of cation M to FES (L/meq),
$[MXf]$: quantity of adsorbed cation M (meq/100g-soil),
$[Xf^-]$: quantity of free site of FES (meq/100g-soil).
Assuming that only Cs is adsorbed to FES at the beginning, that quantity of Cs adsorbed to FES is small enough compared to the quantity of FES, and that all Cs adsorbed to FES is considered exchangeable, equilibrium constant of each cation to FES can be estimated by considering selectivity constant of Cs^+ to K^+ and NH_4^+ for adsorption to FES and by measurement of quantity of exchangeable Cs and the concentration of Cs in the solution, and then, adsorption characteristics of FES can be numerically defined in PHREEQC for calculation of adsorption reaction. Therefore, measurement of concentration of Sr^{2+}, Ca^{2+}, K^+, Mg^{2+}, NH_4^+, and Cs^+ in the solution, their exchangeable quantities, and CEC of the soil can make it possible to estimate equilibrium constants of each cation to RES and FES.

So, some experiments to measure quantity of each exchangeable cation and CEC were carried out, and elution tests by pure water were carried out to measure concentration of each cation in the eluting solution.

In this study, soils got from cedar forest (soil A) and red pine forest (soil B) in the experiment forest of Iwate University were used. The soils were sieved with 2mm sieve, and then, dried one day in 45 °C for the untreated soil or heated one hour in 500 °C for the heat treatment soil. The change of the concentration of each cation was measured for the test of each cation addition to the solution. Experiments using each soil were carried out triplicate and their averages were considered as the measurement values.

RESULTS: Using the equilibrium constants obtained by the experiments, the results of the experiments for the untreated soil and the heat treatment soil were tried to be simulated by the calculation with PHREEQC. Comparing the results simulated by FHREEQC to the results of the experiments, the two results matched each other in the precision of one effective digit regarding Sr, Ca, and K in the case of heat treatment soil. However, the calculated values of the concentration of Cs in the solution were two or three times higher than that obtained by the experiment in the all cases. Regarding untreated soil, simulated concentration of Sr matched in the precision of one efficient digit to that obtained by the experiment in the case of K and NH_4 addition, however, the simulated results was much more different from that obtained by the experiments in the cases of Ca and Mg addition. The simulated concentration of Cs in the solution was 10 to 15 times higher than that obtained by the experiments in the most cases. Especially, the difference was bigger in the case of K addition. To improve the precision of the simulation by FREEQC, it seems necessary to consider adsorption of hydrogen ion, quantity of originally adsorbed Cs at FES and RES, and so on.

CO10-6 An Attempt to Measure Size Distribution of Radioactive Aerosol Particles Produced in an Electron LINAC Facility Using a Diffusion Battery and Imaging Plates

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INTRODUCTION: High intensity accelerators have been developed for various purposes such as isotope production and cancer therapy. Understanding of the nature of radioactive species in air of the accelerator rooms is very important to maintain the safety of accelerator and radiation in the high intensity accelerators.

Radiation-induced aerosol particles in the size range of several nm to ca. 100 nm are produced in addition to radioactive gases in the air of the accelerator rooms during machine operation. The size for the radioactive aerosol particles was often measured using wire screen techniques in accelerator facilities. A combination technique with imaging plate (IP) was employed in a proton accelerator facility [1].

In this work, an attempt was made to measure the size of ^{13}N-bearing aerosol particles using the combination technique of screen-type diffusion battery (SDB) and IPs in an electron linear accelerator facility.

EXPERIMENTS:

Principle of SDB: When very fine aerosol particles pass through a stack of wire screens, a part of the particles is deposited on the wire surface of the screens by their diffusion according to their particle size. The loss by the screens is expressed as a function of particle size, coarseness and number of screens, and flow rate of particles. The radioactivity-based size distribution of the aerosol particles can be calculated by measuring the penetration ratio (A/A_0), where A_0 and A are activity of the nuclide of the aerosol particles before and after penetrating screens, respectively.

Measurement method: The SDB employed in this work consists of 40 pieces of 500-mesh stainless steel wire screen and a backup filter (PTFE membrane filter). After collection of the aerosol particles with the SDB, selected screens and the backup filter were measured with an IP.

Formation and collection of radiation-induced aerosols: The air-irradiation experiment was carried out in the 46-MeV electron LINAC of the Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS). An irradiation chamber was placed at a rear position of a platinum target in the target room. During the irradiation, aerosol-free air was introduced to the chamber from the experiment room next to the target room. The target was bombarded with a 30-MeV electron beam to produce bremsstrahlung. The bremsstrahlung ionizes air and produces the radiation-induced aerosol. The beam current was ca. 100 μA. The irradiated air was sampled with the SDB at the measurement station in the experiment room.

Estimation of size distribution of radioactive aerosol particles: The IP image of the selected screens and the backup filter was simultaneously taken using a single large IP (Size: 43 x 35 cm). The penetration ratio for the i-th screen was calculated by the dividing total activity of the screens downstream of the i-th screen and the backup filter by the total activity of all screens and the backup filter. In this calculation, the activity of each 500-mesh screen was estimated by fitting of the intensity of photostimulated luminescence (PSL) of the measured 500-mesh screens.

RESULTS: A part of the irradiated air was introduced to an SMPS (Scanning Mobility Particle Sizer) to monitor the number-based aerosol size simultaneously with the SDB collection. A stable lognormal size distribution was observed during the collection of the aerosol by the SMPS measurement.

The penetration ratio for each screen was calculated as described above. The curve of the penetration ratios was fitted to a theoretical function [2] for lognormal distributions to obtain the geometric mean and geometric standard deviation of particle diameter. When the air was introduced to the chamber and the SDB at the same flow rate of 12 L/min, the preliminary result of the size was ca. 60 nm.in diameter, which coincided with the particle size previously reported by another method [3].

Most of ^{13}N atoms formed in the air exist as gas forms in accelerator rooms. Even a small amount of condensation of acidic radioactive gases like $H^{13}NO_3$ gas on the screen surface may influence greatly the estimation of aerosol size. An effective compensation technique was discussed to eliminate the influence.

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