IMPORTANT MODEL PARAMETERS FOR ANALYZING ACTIVATION EFFECTS IN ACCIDENT SCENARIOS FOR HEAVY-ION MEDICAL ACCELERATOR FACILITY

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To find the important model parameters that govern the radiological effects is the first step to analyze the accident scenarios for the facility, since the facility produces high energy charged particle beams and accidental release to the environment of induced radioactive nuclides may cause harmful effects on various organisms constituting an ecosystem. In addition, the use of optimized model parameters reduces the simulation efforts and is helpful to get reasonable decision criteria. The combination of MCNPX2.7.0 and visual CINDER, the best activation simulation tools in the world, is used in this study. Simulations of generic airborne radioactivity were performed by using simplified geometry models with an air-filled chamber of inside dimensions of 5m x 5m x10m for non-clinical area and of 8m x 5m x 10m for clinical area. For the non-clinical area, a cylindrical target of a lead, length of 20 cm and radius of 5 cm, was used to ensure a high neutron production. On the other hand, a cylindrical water phantom with length of 35cm and radius of 15 cm was used to simulate the patient body. The following parameters were used for the calculation of the radiological exposure caused by the air activation: (1) maximum annual number of accelerated particles; (2) maximum number of accelerated particles per second; (3) volume of the treatment room and the accelerator hall; (4) ventilation rates in the individual rooms. For the calculation of the average specific activity of the air that is discharged to the environment, it was assumed that about 14 000m3 of air was renewed per hour. On the other hand, clinical room air circulation rate was 20 minutes.

I. INTRODUCTION

The number of heavy-ion medical accelerator facilities is increasing worldwide because the heavier ion beams such as carbon 12 ions are known to be the most effective therapy for certain kinds of cancers [1]. During the beam operation, radioactive air is generated by both the normal operation and the accidental beam loses in the system. To find the important model parameters that govern the radiological effects is the first step to analyze the normal and accidental scenarios for the facility since the facility produces high energy charged particle beam such as 430 MeV/u carbon 12 ion and accidental release to the environment of induced radioactive nuclides may cause harmful effects on various organisms constituting an ecosystem. In addition, the use of optimized model parameters reduces the simulation efforts and is helpful to get reasonable decision criteria.

Air activation is a huge concern not only for the employees but also for the public and for the environment because radioactive air can be released uncontrollably. Thus, a systematic study for analyzing air activation of heavy-ion medical accelerator facility with 430 MeV/u carbon 12 ions was carried out in this study. The combination of MCNPX2.7.0 [2] and visual CINDER codes, the best shielding and activation simulation tools in the world, is used. Visual CINDER code [3] is the wrapped version of original CINDER'90 [4] and CINDER2008 [5] codes with a visual C#.NET programming language. For the original CINDER codes, the "Activation Script" reads most of the problem information such as cell properties, material compositions and neutron fluxes which are generated from the MCNPX code. With their own input files, CINDER codes produce nuclear inventory for a requested list of MCNPX cells and for a requested time history. A second script extracts the decay photon sources from CINDER outputs for a requested list of cells and for a requested irradiation or decay time step and builds source deck for subsequent MCNPX calculation.

The real accelerator hall is significantly greater than the generic simulation geometry. Exponential volume correction law was developed to account for the system size influence. For the conservative estimation of the exposure of staff members by inhalation, a maximum value between tabulated dose conversion coefficient and computed value by using regal unrestricted release limit for each radionuclide was chosen. The fundamental physical processes that determine the airborne radionuclide production are spallation processes of high-energy primary beam to produce an offspring with the surrounding air (e.g., the production of C-11 or Be-7) and the capture of low-energy neutrons (e.g., the production of Ar-41). We assume that the ventilation is switched off during the irradiation and cooldown, which represents the highest concentration of radionuclides.

Radiological consequences of the air activation discharged to the environment were compared with the release limits for exhaust gas enforced in the “Korean Radiation Protection Law”. The averaged over the year total value for all isotopes can be specified for the sum of all irradiation modes, resulting in a safe value of lesser than 1.0. To reduce the activity of air discharged out onto the environment, the air exchange rate of the accelerator hall should be reduced during operation of the beam to a minimum. However, before access to the accelerator room, ventilation should be set to maximum fan speed to minimize the exposure of radiation to a staff entering the room. Furthermore, it must be ensured through ventilation that the air is well mixed in the irradiation chambers to exclude areas of greatly increased airborne radioactivity. The air must be filtered before it is discharged to the environment to remove the aerosol-bound radionuclides such as Iodine and Cesium from the exhaust air.

II. METHODS AND MATERIALS

I.A. Geometrical Model Description

Simulations of generic airborne radioactivity were performed by using simplified geometry models with an air-filled chamber of inside dimensions of 5m x 5m x10m for non-clinical area and of 8m x 5m x 10m for clinical area. In the non-clinical geometry, two target positions were provided to analyze the different productions of radionuclide by the primary beam and the secondary particles generated by the impact of the primary beam to the target. For the clinical geometric model, model size is approximately the same as the real facility clinical area. Thus, there is no need of size effect conversion. For the non-clinical area, a cylindrical target of a lead, length of 20 cm and radius of 5 cm, was used to ensure a high neutron production. On the other hand, a cylindrical water phantom with length of 35cm and radius of 15 cm was used to simulate the patient body.

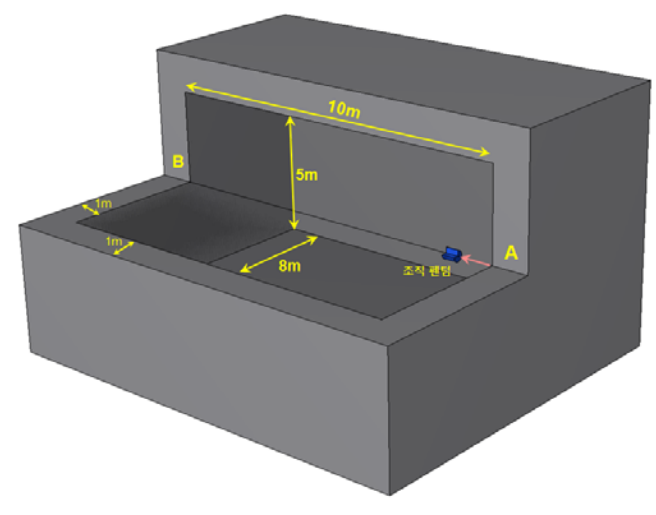

Fig.1. Geometry for computing clinical area air activation. In an air-filled chamber with the inside dimensions of 10 m × 8 m × 5m a phantom target is shown. The target position is arranged centrally in the room and one meter away from the wall A. The air of the room is surrounded by concrete walls (1 m thick) to support the back-scattering of secondary particles.

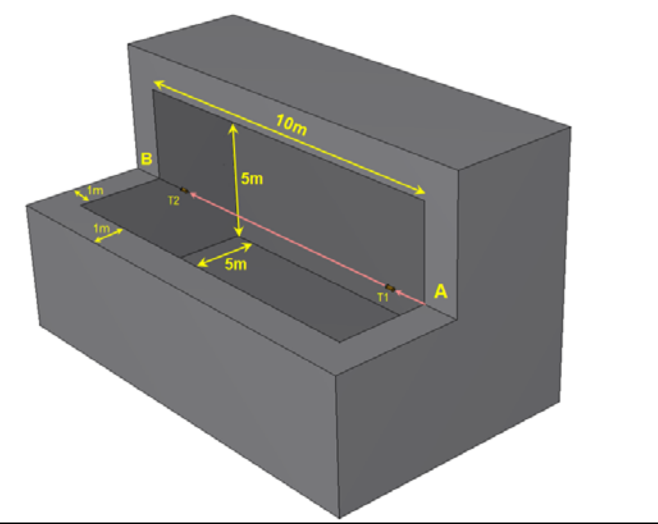

Fig.2. Geometry for non-clinical area air activation. In an air-filled chamber with the inside dimensions of 10 m × 5 m × 5m two target positions (denoted by T1 and T2) are provided. These target positions are arranged centrally in the room and one meter away from the walls A and B respectively. The air of the room is surrounded by concrete walls (1 m thick) to support the back-scattering of secondary particles.

The beam is launched in both simulations directly behind the wall A and sent either to the target T1 or T2. In the simulation, the investigated target position T2, the target T1 is removed and the beam passes through the entire room before it hits the target T2. The production of radionuclides can be split basically into two contributions: (1) Radionuclide by the primary beam and (2) radionuclide by secondary particles generated by the impact of the beam on the target. Primary beam effects occur more when the beam first passes through a large part of the room before it hits the target, whereas secondary beam effects are more pronounced when the target is placed at position T1 by the enlargement of the path length of the secondary particles in air.

The fundamental physical processes that determine the airborne radionuclide production are, on the one hand, spallation processes of high-energy primary beam or the high-energy. Offspring with the surrounding air is, for example, the production of C-11 or Be-7 and on the other hand, the capture of low-energy neutrons is, for example, the production of Ar-41. In the simulations for the clinical case, a cylindrical water target is occupied at the T1 position. Thus, on the basis of the similarity of the secondary production of this scenario with the secondary production which occurs in a real clinical radiation, these simulation results can be used to calculate the airborne radionuclide in the clinical operation.

I.B. Visual CINDER code

CINDER code, CINDER'90 or CINDER2008 that is integrated with the Monte Carlo code, MCNPX, is widely used to calculate the inventory of nuclides in irradiated materials. The MCNPX code provides decay processes to the particle transport scheme that traditionally only covered prompt processes. The integration schemes serve not only the reactor community (MCNPX burnup) but also the accelerator community as well (residual production information). For the accelerator community, the integration scheme requires additional scripts to prepare multiple steps computing as shown in Fig.3.

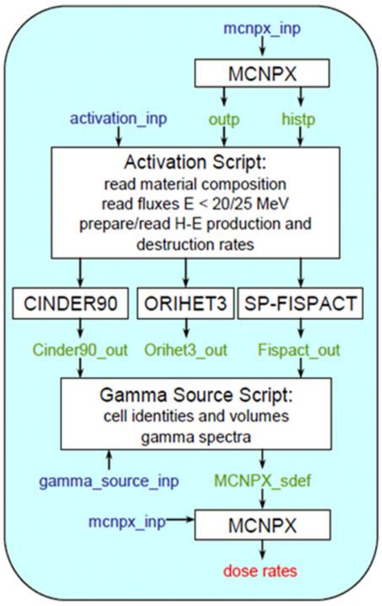

Fig. 3. Flow diagram of an activation analysis employing the activation script and the gamma source script with the MCNPX radiation transport code.

Figure 3 shows the general flow of computing procedures which combines with the MCNPX and Perl scripts. Because the task of extracting isotope production rates and flux spectra from MCNPX output and "histp" files is the same for performing activation analyses with other transmutation codes such as ORIHET3 and SP-FISPACT, the scripts were extended to serve and execute simultaneously with these transmutation codes. The big benefit for providing these options lies in the easy cross comparison of the transmutation codes since the calculations are based on exactly the same material, neutron flux and isotope production/destruction inputs. However, it is just frustratingly cumbersome to use. In addition, multiple human interventions may increase the possibility of making errors. The number of significant digits in the input data varies in steps, which may cause big errors for highly nonlinear problems. Thus, it is worthwhile to find a new way to wrap all the codes and procedures in one consistent package which can provide ease of use.

Since CINDER code is written in FORTRAN, first we need to build FORTRAN code into a DLL (Dynamic Link Library) to call them from C# code, and then use Platform Invoke, a service that enables managed code to call an unmanaged function or subroutines inside the DLL. Platform Invoke service locates and calls unmanaged code as an exported function. It also marshals the call's arguments, such as input and output parameters, integers, strings, arrays, and structures, as needed. It is recommended to wrap the FORTRAN function or subroutine in a managed class. Within the class, you define a static method for each FORTRAN function or subroutine to be called. The "DllImportAttribute" is used to identify the DLL and function. The definition can include additional information, such as the calling convention used in passing method arguments. Figure 4 shows unmanaged FORTRAN code calling schemes in combination with the managed C# main code.

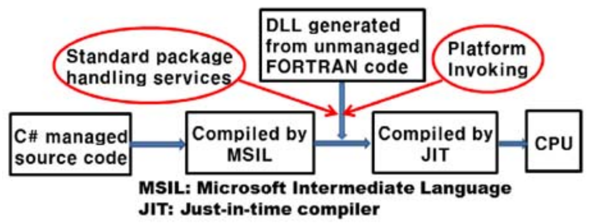

Fig. 4. Schematic diagram to handle DLLs generated from unmanaged FORTRAN code.

Visual Studio is the IDE in which developers can create programs in C# for the .NET framework. It is used to create console and graphical user interface (GUI) applications along with Windows Forms or Windows Presentation Foundation (WPF) applications, web applications, and web services in both native code together with managed code for all platforms supported by Microsoft Windows, Windows Mobile, Windows CE, .NET Framework, .NET Compact Framework and Microsoft Silverlight. The data generated by CINDER code can be shown in a succinct image. Data created by radiation transport and transmutation simulations can be referred to as a "Big Data". Thus, processing, analyzing and communicating this data present a variety of ethical and analytical challenges for data visualization. The visual CINDER code includes 2D and 3D graphics utilities to help address this challenge. In addition, the original CINDER code produces a maximum of about 60 text data tables. The size of each table has no preset limit, so text file handling is also a big challenge. Practically, many researchers use the Microsoft Excel spread sheet to handle these files, which is tedious and time consuming work. Visual C#.NET can provide many functions to generate Microsoft Office stub such as Excel or Word, and many manual tasks can be automated. The visual CINDER code implements these utilities and writes the data set in an excel spread sheet automatically.

I.C. Operation Scenarios

Beam operation scenarios are divided into three categories: (1) clinical room area, (2) research room area, and (3) accelerator hall. In each area, we assume two operations: (1) normal operation and (2) accidental beam loss. Each case can again be divided by the different air ventilation modes. In normal beam operation of the treatment room, carbon 12 ion beam with energy of 430 MeV/u and beam intensity of $1\text{x}10^9$ particles per second is irradiated to the patient during 120 seconds for 1 fraction of treatment. For the conservative estimation, no air ventilation is assumed. Two accident scenarios for the treatment room are also performed; maximum intensity of beam loss for one hour with no air ventilation and with three times of complete air ventilation (20 minutes per one complete air ventilation is assumed).

Normal operation of research room operation is assumed to be five minutes of continuous maximum intensity beam irradiation with the beam energy of 430 MeV/u and no air ventilation for the conservative estimation. Two accident scenarios of research room operation are 20 minutes and one hour of continuous beam losses. Equivalent dose rates are estimated for the one hour stay of the room without knowing the accidental beam losses. Before being released to the environment during normal operation, main portion of the activated air in the accelerator hall region is introduced into hall to extend the decay time of the isotopes. In normal operation, beam loss of accelerator hall is very small compared with the treatment room and research room. Thus, an accident scenario is performed for the accelerator hall. Twenty-four hours of beam loss were occurred and an employee entered the hall without knowing the beam loss and stayed there for one hour. Effective dose and dose rate were estimated for each beam irradiation scenario. The calculation methods of effective dose rate and dose are introduced in the next subsection.

I.D. Estimations of Space Size Influence and Radiological Impact (Effective Dose Rate)

I.D.1. Estimation of Space Size Influence

The air activation was estimated for all scenarios with simulation geometry of a room the size of 10 m × 5m × 5m. The real radiation rooms and especially the accelerator hall are significantly greater. To account for this fact, we simulated air activation for the other geometry with a four-fold increased volume (10m × 10m × 10m). The averaged over the year value (specific activities / permitted limit) in the case of four time magnified area shows 36% higher than in the case of the original geometry space for the generic study. The concept of effective dose refers to the dose received by the person by the presence in radioactive gas in the subsequent 50 years in this study, by following the international regulation committees such as IAEA.

This space size effect is extrapolated for an estimation caused by the different spatial size by following equation:

$$\text{Radiological impact of new volume (V1)} = \text{Radiological impact of old volume (V) x } (v1 / v)^p \quad (1)$$

The value of the exponent p is obtained from the comparison of the above result with the result of the generic study of ln (1.42) / ln (4). Thus, the value varies a little bit depending on the simulation geometry because of the errors inherent of the probabilistic computing. However, it does not vary big. In our simulations, it varies from 0.20 to 0.23. We use more conservative value in this analysis.

I.D.2. Calculation of Radiological Impact: Conversion of Activity to Effective Dose Rate

This section deals with the production of airborne radioactivity that arises per primary particles such as carbon ion. The evaluations of the air activation require many parameters such as beam intensities, room size, courses of irradiation and decay, and ventilation rate in individual room.

The calculation of the nuclide in a given volume of air depends on energy and path length of protons, neutrons and positively or negatively charged ions in the air volume and is done by the MCNPX Monte Carlo particle transport code and transmutation computing code CINDER. Conversion of the path lengths to the associated production rate P_i of radionuclide *i* can be performed by the following equation:

$$P_i = \sum_{j,k} n_j \int dE \sigma_{i,j,k}(E) \Lambda_k(E), \quad (2)$$

where n_j is atomic density of the element j in the air, $\Lambda_k(E)$ energy-dependent path length of the different type of particle *k*, $\sigma_{i,j,k}(E)$ energy dependent cross section for the production of radionuclide *i* from the reaction of the particle type *k* with the isotope *j*. In this study, the air was adopted with the following parameters: (a) density of 1,205kg/m^3 and (b) percentage composition by weight as follows: N_2 = 75.51%, O_2=23.15%, Ar =1.29%, CO_2=0.05%. The cross sections of the individual elements were taken into account with their natural isotopic composition.

Calculation of the accumulated radioactive air by staying in subsequent dose rate uses the following parameters: (a) production of airborne radioactivity per carbon ion which was calculated for the model space, (b) beam intensity, irradiation time and decay time before admission, (c) volume of the respective space, (d) air exchange rate of the individual rooms, (e) conversion factor of specific airborne radioactivity (Bq/m^3) in accumulated dose per unit hour. The specific air activity after irradiation and after the decay in the room for all isotopes *i* is calculated as follows:

$$A_i(t_{irr} + t_{cool}) = \frac{P_i I}{V}(1 - e^{-\lambda_i t_{irr}})e^{-\lambda_i t_{cool}}, \quad (3)$$

where P_i is the total activity of the isotope *i*, produced in the air per carbon ion, t_{irr} : irradiation time, t_{cool} cool down time, I intensity of carbon ions per second, *V* volume, and λ_i decay constant of radionuclide *i*.

Radiological impact of a person is the measure of the radiation exposure of a person by staying in the radioactive air (given by the specific isotope-dependent activities of the air in Bq/m^3). Subsequent dose rate is the dose absorbed and accumulated by spending per unit of time (e.g. an hour) in the radioactive atmosphere over the next 50 years. In other words, isotopes, can be inhaled (e.g. hour) in a certain unit of time, may be deposited in the body and therefore expose the body even after leaving the radioactive atmosphere.

Effective dose component (*E*) from the intake by inhalation is given by the product of dose coefficient and incorporated activity for each radionuclide:

$$E = \sum_j h_j(e) J_j(e), \quad (4)$$

where $h_j(e)$ is dose conversion coefficient and $J_j(e)$ inhaled activity for each radionuclide *j*. Inhaled activity is the product of specific activity, respiration rate, and residence time (or exposed time):

$$J_j(e) = \frac{A}{V_{room}} \dot{V}_r t_e, \quad (5)$$

where A is total activity, V_{room} room volume (A/V_{room} :specific activity), $\dot{V}_r$ respiration rate, and t_e exposed time.

Activity concentrations of radioactive nuclide in discharges are needed for the calculation of the absorbed isotope-dependent effective dose rate per Bq/m^3. For example, the annual subsequent absorbed dose in a person (respiratory rate: 1.2 m^3/hour) by inhalation, who is staying more than a year in an activated air atmosphere with the radionuclide concentration C_i, is calculated as follows:

$$\frac{Dose}{Year} = 24\, {}^{h}\!/_{d}\, x 365\, {}^{d}\!/_{y}\, x 1.2\, {}^{m^3}\!/_{h}\, x C_i x h(e)_{\max}. \quad (6)$$

Activity concentration C_i is given by the table values *a priori*. However, for the conservative estimation, it is again estimated from the annual effective dose for the public such as 1mSv/year, according to the Korean Radiation Protection Ordinance as follows:

$$\frac{SubsequentDoseRate}{SpecificAirActivation}:\frac{\left(\frac{\mu Sv}{h}\right)}{\left(\frac{Bq}{m^3}\right)}=\frac{\frac{1000}{24x365}}{C_i} \qquad (7)$$

If the calculated annual effective dose is higher than 1 mSv, the radionuclide concentration Ci is assigned a new, more conservative Ci value by using the following equation:

$$C_i^{new}=C_i^{old}\,x\,\frac{\frac{1000\mu Sv}{year}}{\frac{ComputedDose}{Year}} \qquad (8).$$

This ensures the conservative values at all limits.

III. RESULTS AND DISCUSSION

For the evaluation of a system size effect, we estimated the radiological impact for two different size systems, 4 x 5 x 10 m3 and 8 x 10 x 10 m3 so that four times different size systems were compared. Radiological impact increased about 42%, from 0.537 to 0.763. Thus, the exponential factor, $\ln(1.42)/\ln(4)$, is about 0.253. We extrapolate the results with this exponential factor for all variable system size. Actually, we experimented many different size systems and noticed that the exponential factor varied from 0.2 to 0.3. In this way, we can estimate the radiological impact of the accelerator hall by using generic model with the assumption of the achievement of uniform air circulation over the whole area. Table I shows some of the detail result.

TABLE I. Volume size dependency effect. About 42% increased by increasing space of 4 times big.

NUCLIDE	HALFLIFE	Specific Activity(Bq/m^3)		Unrestricted release limit (Bq/m^3)	Ratio (radiological impact)	
		4 x 5 x 10 m^3	8 x 10 x10 m^3		4 x 5 x 10 m^3	8 x 10 x10 m^3
H 3	3.89E+08	2.24E-02	3.18E-02	2,000	1.12E-05	1.59E-05
Be 7	4.61E+06	3.32E-01	4.42E-01	1,000	3.32E-04	4.42E-04
Be 10	4.77E+13	1.29E-08	1.73E-08	2	6.44E-09	8.64E-09
C 11	1.22E+03	6.04E+02	8.47E+02	20,000	3.02E-02	4.24E-02
C 14	1.80E+11	8.88E-06	1.12E-05	100	8.88E-08	1.12E-07
…	...	...	...	...	...	...
P 33	2.19E+06	9.11E-03	3.42E-02	50	1.82E-04	6.83E-04
S 35	7.56E+06	5.93E-03	1.20E-02	50	1.19E-04	2.39E-04
S 38	1.02E+04	8.67E-01	1.73E+00	423	2.05E-03	4.10E-03
Cl 34*	1.93E+03	1.45E+00				
Cl 36	9.50E+12	1.42E-08	2.36E-08	10	1.42E-09	2.36E-09
Cl 38	2.23E+03	4.07E+01	6.60E+01	1,000	4.07E-02	6.60E-02
Cl 39	3.34E+03	2.74E+01	5.16E+01	1,000	2.74E-02	5.16E-02
Ar 37	3.03E+06	3.79E-02	5.44E-02	700,000,000	5.41E-11	7.77E-11
Ar 39	8.49E+09	4.06E-05	5.90E-05	200,000	2.03E-10	2.95E-10
K 40	4.03E+16	1.24E-13	1.24E-13	30	4.13E-15	4.13E-15
				Sum	**5.37E-01**	**7.63E-01**

With the assumption of one fraction of patient treatment, 120 seconds of irradiation of carbon 12 ions with the intensity of 1 x 10^9 pps and the maximum energy of 430 MeV/u (we assume here the maximum energy for the conservative estimation), we estimated the radiological impact of a treatment practitioner who entered the treatment room just after irradiation of one fraction of treatment and prepare the next treatment during 20 minutes. Although the air ventilation is set for 20 minutes, we assume no ventilation during this period of time for the conservative estimation. The result is shown in Figure 5. Dose rate and integrated dose are shown after a fraction of beam operation as a function of time after the end of irradiation. Since, in a clinical operation, the time period between two irradiation cycles is longer than 20 minutes, a complete air exchange can be performed during this period. Therefore, this scenario can be used as a realistic estimate of the air activation and its consequences for the staff.

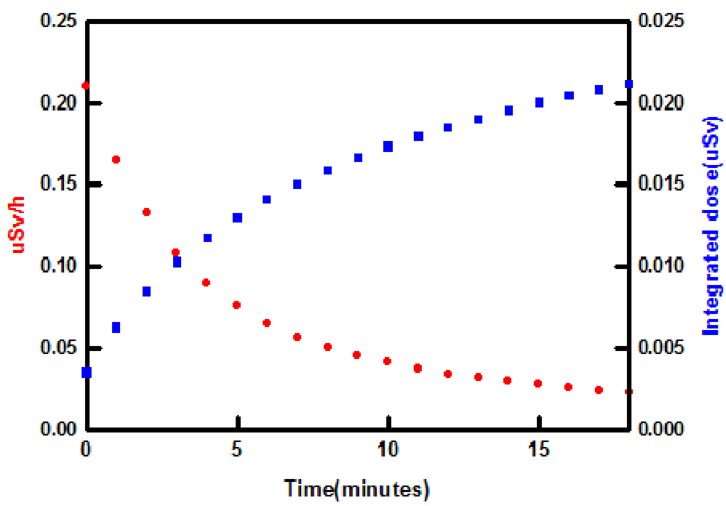

Fig.5. Normal treatment scenario: Effective dose and dose rate estimation for treatment personnel.

We made an accident model for the clinical room. Specifically, this type of accident can be occurred during quality assurance. We assume that the air ventilation is out of order without notice and one hour of continuous irradiation of carbon 12 ions on the water phantom with the maximum energy of 430 MeV/u and maximum intensity of 1 x 10^9 pps. Without any notice, a staff member entered the treatment room and worked for one hour. By inhalation, consequent radiological impact is shown in Figure 6. Dose rate and integrated dose are shown after an hour beam operation as a function of time after the end of irradiation. One hour residence corresponds to total dose of about 0.2 µSv, which is 4 times smaller than initial dose rate (0.9 µSv /h) due to decay of the short lived isotopes. Although the calculated effective dose rate is below 1 µSv/h, the receipt must be verified by measurement.

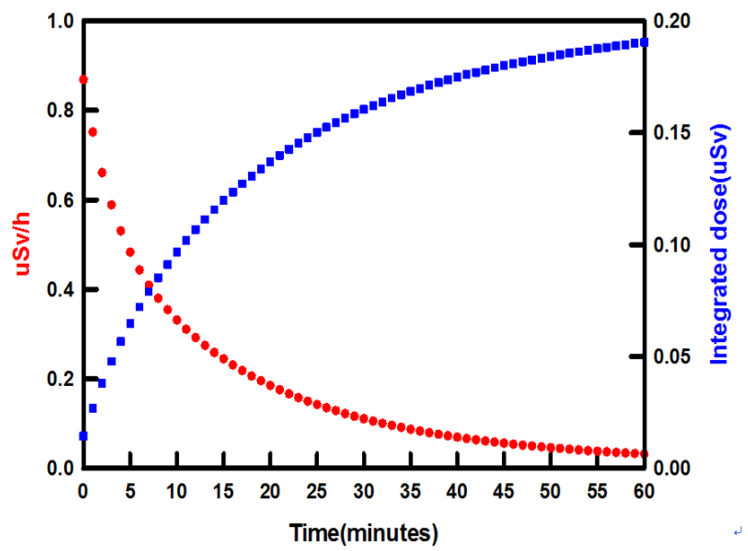

Fig.6. Accident scenario in treatment room: Effective dose and dose rate estimation for a staff.

Non clinical research room uses a lead target which produces abundance of secondary neutrons. We made two accident models, 20 minutes continuous irradiation with no ventilation and one hour of continuous irradiation. Because our design of air ventilation is 20 minutes for the clinical and research rooms, these scenarios actually simulate the normal and abnormal function of ventilation system. For the conservative estimation, we assume the maximum energy of 430 MeV/u and maximum intensity of 1 x 10^9 pps in these scenarios.

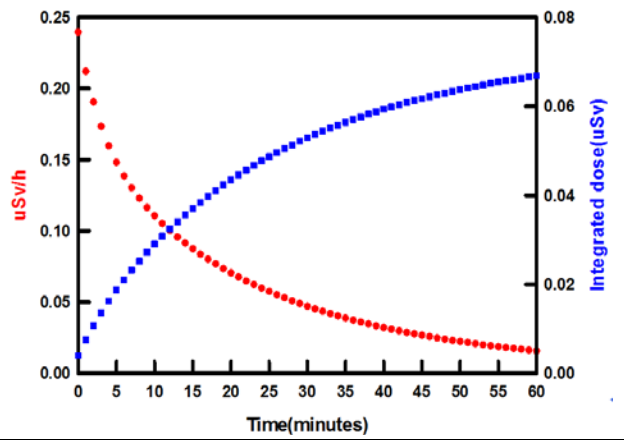

Fig. 7. Accident scenario for non-clinical research room for 20 minutes irradiation.

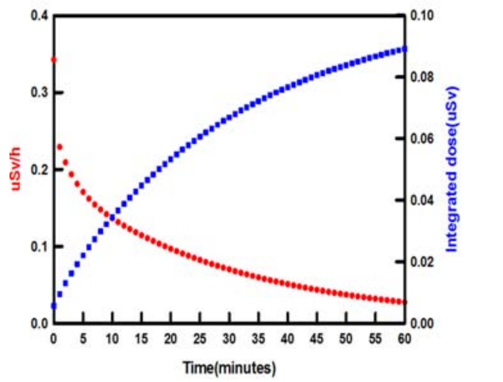

Fig. 8. Accident scenario for non-clinical research room for one hour irradiation.

Dose rate and integrated dose are shown after 20 minutes and an hour beam operation as a function of time after the end of irradiation. Due to the dominance of short-lived isotopes (O-15, N-13, C-11), no linear relationship is seen between exposure time and air activation. Ventilation effect is not clear but dose rate is reduced due to the reduction of the intensity of isotopes.

Accelerator hall is different from research and clinical rooms in size and beam irradiation intensity. Modeling and simulation size is small, compared with that of real accelerator hall. Thus, size effect must be included and also uniform mixing of activated air is assumed although it is unrealistic. However, beam loss and energy are small, compared to the irradiation room such as research room. For the conservative estimation, we assume the maximum intensity of 1 x 10^9 pps of beam loss and maximum energy of 430 MeV/u in the accelerator hall in this study. The scenario is that 24 hours of maximum intensity and maximum energy beam loss were occurred for 24 hours with no detection. A staff entered the hall and worked for an hour. By inhalation, the dose rate and total dose are calculated as shown in Figure 9.

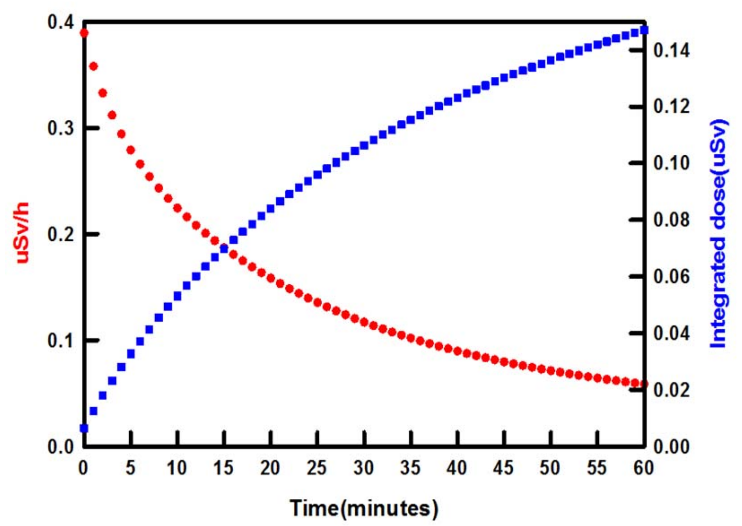

Fig.9. Accident scenario in treatment room: Effective dose and dose rate estimation for a staff.

Dose rate and integrated dose are shown for an hour stay as a function of time after the end of irradiation. Immediately after the end of irradiation, the "committed dose rate by inhalation“ is 0.4 μSv / h. For a stay of one hour in the room, a subsequent dose of about 0.15 μSv is received. When we apply volume rescale equation to these results for taking into account the increased volume effect, these values must increase by a factor of 2.5. In addition, due to the full time decay of short lived isotopes, initial dose rate is reduced exponentially.

II. CONCLUSIONS

We studied the safety against the radiological impacts for the surrounding environment and personnel in the new heavy-ion treatment accelerator facility. Clinical and research operations were studied for the normal and accident cases and radiological impact in the form of effective dose rate and total dose were calculated by using MCNPX and CINDER codes. Several important parameters for the analysis of air activation in the heavy-ion accelerator facility were deduced. The effects of primary reaction and the secondary reaction were analyzed separately. We found that spallation effect is important in primary reaction. Meanwhile low-energy neutron capture is important in secondary reaction.

System size dependency is also important to estimate the effective dose in the accident scenario of the accelerator hall. Although there is a little bit of statistical variations, it is enough to make a model to estimate the whole size by using generic simulation model. The estimation of effective dose and dose rate from the specific activity for the clinical personnel is very important. Specifically, total effective dose per year for the treatment personnel is important and out result showed that it is almost equivalent to the amount of natural environment dose in this area. For the conservative calculation, we choose the maximum dose conversion intensity (C_i) in this study.

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