

### **1A01 Measurement of the excitation functions of Np isotopes in U+p and Th+Li reactions.**

HAYAKAWA, Y.<sup>1</sup>, SAKAGUCHI, A.<sup>2</sup>, MURATA, M.<sup>1</sup>, MATSUMURA, N.<sup>1</sup>, FUJINUMA, S.<sup>2</sup>, NAKAJIMA, A.<sup>2</sup>, KASAMATSU, Y.<sup>3</sup>, SHINOHARA, A.<sup>3</sup>, KOMORI, Y.<sup>4</sup>, YOKOKITA, T.<sup>4</sup>, MORI, D.<sup>4</sup>, YANOU, S.<sup>4</sup>, HABA, H.<sup>4</sup>, YOKOYAMA, A.<sup>1</sup>

(<sup>1</sup>Kanazawa University, <sup>2</sup>University of Tsukuba, <sup>3</sup>Osaka University, <sup>4</sup>RIKEN)

A naturally occurring nuclide, <sup>237</sup>Np ( $t_{1/2} = 2.1 \times 10^6$  y), is analyzed by using a short-lived Np isotope or a Pu isotope considered similar in a chemical behavior, but there is no tracer that is more satisfactory in its determination. Because <sup>236g</sup>Np ( $t_{1/2} = 1.5 \times 10^5$  y) is long-lived and can be applied to Accelerator Mass Spectrometry (AMS), it has been a candidate as a tracer for determination of Np for years. However, no production method has been established for the nuclide. In this study, nuclear reactions of U + p and Th + Li were carried out to produce Np isotopes and their yields were measured by  $\gamma$ -ray spectrometry and AMS. It was found that the <sup>234</sup>Np, <sup>236g</sup>Np, <sup>236m</sup>Np and <sup>237</sup>Np nuclides are produced in the reactions. Compared to the U + p reaction, cross sections of Np isotopes in the Th + Li reaction are smaller, while m/g ratio of <sup>236g</sup>Np is more favorable than U + p reaction. In this paper, in addition to m/g ratio, the formation ratio of Np-237 to Np-236g is also discussed.

### **1A02 Measurements of Excitation Functions for the <sup>nat</sup>W(d,x) Reactions and Half-lives of Rhenium Isotopes**

KOMORI, Y.<sup>1</sup>, MURAKAMI, M.<sup>1,2,3</sup>, HABA, H.<sup>1</sup>

(<sup>1</sup>RIKEN Nishina Center, <sup>2</sup>Grad. School of Sci. and Technol., Niigata Univ., <sup>3</sup>JAEA)

We are conducting model experiments for chemical studies of element 107, Bh, using long-lived radiotracers of its homolog, Re: <sup>183</sup>Re ( $T_{1/2} = 70$  d) and <sup>184m</sup>Re ( $T_{1/2} = 169$  d). In this work, excitation functions of deuteron-induced nuclear reactions on natural tungsten have been measured up to 24 MeV for the quantitative production of these Re isotopes. The target stack of W/Ti foils was irradiated for 1 h with a 24-MeV deuteron beam supplied from the RIKEN AVF cyclotron. After the irradiation, each foil was subjected to  $\gamma$ -ray spectrometry. The beam current of 0.18  $\mu$ A was determined by the monitor reaction <sup>nat</sup>Ti(d,x)<sup>48</sup>V. In this work, we could measure the excitation functions for the production of <sup>181,182a,182b,183,184m,184g,186g</sup>Re, <sup>187</sup>W, and <sup>182g,184</sup>Ta in the <sup>nat</sup>W(d,x) reactions. We discussed them by referring to the previously reported data and the theoretically evaluated data in the TENDL-2017 library. Thick-target yields for the investigated isotopes were also deduced from the measured excitation functions. Through the radioactivity measurements, we noticed that the half-lives of some Re isotopes such as <sup>181,183</sup>Re are slightly

shorter than those adopted in the current nuclear database. Therefore, we precisely measured their half-lives in the separate experiments. We found that the half-lives of  $^{181,183}\text{Re}$  and  $^{184\text{m}}\text{Re}$  are almost 5% shorter and longer than those in the current database, respectively.

### **1A03 Production of p-nuclei in the Ia supernova**

KINOSHITA, N.

(Shimizu Co.)

Thousands of nuclei are synthesized in tens milliseconds under extremely high temperature and pressure which are achieved by supernovae and neutron star mergers. The nuclides are synthesized in a complicated network of nuclear reactions by photon, neutron, proton, alpha particles, and decay. The p-nuclei, neutron deficient nuclei which are not produced by a neutron capture reaction, are mainly synthesized by Ia supernovae (IaSN). Thousands of reaction rates of the nuclear reactions depend on theoretical model, although several nuclear reactions for the synthesis are experimentally confirmed. In the present work, I performed the network calculation of the nucleosynthesis in the supernova condition obtained by the W7 model using the reaction rates calculated with different parameters for the optical model and level density in the Hauser-Feshbach calculation. Production yields of the p-nuclei showed different feature regardless of the nuclear model. The mixing of the products synthesized in supernovae with a different Pb/Fe ratio would be required for the explanation of solar abundance. On the other hand,  $^{98}\text{Tc}/^{96}\text{Ru}$  and  $^{146}\text{Sm}/^{144}\text{Sm}$  ratio produced in the supernovae were at least tens times larger than the abundances in the primitive solar system.

### **1A04 Simultaneous Production and Separation of Carrier-free Alkali Metal Tracer Using Photonuclear Reaction**

IKEDA, H.<sup>1,2</sup>, KIKUNAGA, H.<sup>2</sup>, WATABE, H.<sup>1</sup>

(<sup>1</sup>Cyclotron and Radioisotope Center, Tohoku University, <sup>2</sup>Research Center for Electron Photon Science, Tohoku University)

The demand for carrier-free RI tracers is increasing to understand the behavior of alkali metals in plants. In Japan, when performing experiments using K tracer, it has to be produced by an accelerator each time. If other alkali metal tracers can be produced simultaneously with the K tracer, efficient experiments can be performed in time and economy. In this study, the conditions for simultaneous production and separation for carrier-free mixture RI tracer of K, Rb and Cs were determined and demonstrated.

The CaO, SrO and BaO pellets in a quartz tube were irradiated with bremsstrahlung radiation. Water and oxalic acid (H<sub>2</sub>C<sub>2</sub>O<sub>4</sub>) solution were added to the irradiated target to precipitate. The supernatant was separated by centrifugation and it was charged to a cation exchange column (2 mL). The column was flushed with 20 mL of 0.01 M HCl. It was eluted with concentrated (11.5 M) HCl to create elution curves.

12% of K-43, 15% of Rb-86, and 9% of Cs-136 were coprecipitated with oxalate (mixture of CaC<sub>2</sub>O<sub>4</sub>, SrC<sub>2</sub>O<sub>4</sub> and BaC<sub>2</sub>O<sub>4</sub>). Most of the alkali metal was eluted with about 4.0 mL of concentrated HCl. We demonstrated that carrier-free mixture RI tracer of K, Rb and Cs can be produced and separated simultaneously.

#### **1A05 Production of At-211 at RIKEN**

WANG, Y., SATO, N., KOMORI, Y., YOKOKITA, T., MORI, D., USUDA, S., HABA, H.  
(Nishina Center for Accelerator-Based Science, RIKEN)

The 7.214-h half-life radioisotope <sup>211</sup>At offers many potential advantages for targeted  $\alpha$ -particle therapy. We developed a production technology of <sup>211</sup>At at the RIKEN RI Beam Factory to distribute this useful radioisotope to the researchers in Japan. A 29-MeV alpha beam was extracted from the RIKEN AVF cyclotron. After passing through a Be vacuum window and He cooling gas, the energy on the target was about 28 MeV. <sup>211</sup>At was produced via the <sup>209</sup>Bi( $\alpha$ ,2n)<sup>211</sup>At reaction by irradiating a metallic Bi target for 2 to 8 hours at beam intensities between 2 and 16  $\mu$ A. The irradiated Bi target was measured using a Ge detector, and the thick target yield (TTY) agreed well with the literature data. <sup>211</sup>At was separated from the irradiated Bi target by a dry distillation technique in a quartz column (850 °C) with O<sub>2</sub> carrier gas (10 mL/min). The separated <sup>211</sup>At was dissolved with chloroform, and was dried up by a N<sub>2</sub> gas flow (100 mL/min) at a room temperature. The typical chemical yield was about 80%.

#### **1A06 Development of thermochromatography apparatus for accurate measurement of adsorption temperature of At compound in gas phase**

ICHIMURA, S., OBATA, H., NAKAGAWA, S., TERAMOTO, T., OOE, K., NAGATA, K., TOYOSHIMA, A., YOSHIMURA, T., SHINOHARA, A.  
(Osaka Univ.)

We have been developing a thermo-chromatography apparatus to separate and identify At compounds produced by dry distillation. In our previous study, accuracy was insufficient in the column temperature and the deposition position of <sup>211</sup>At for the apparatus. In the present study,

we improved the apparatus to solve the accuracy problems; temperature stability is largely increased by using 10 independent heaters and adsorption position of  $^{211}\text{At}$  can be precisely determined with an automated CdTeZn detector with a 2-mm collimator. In an experiment,  $^{211}\text{At}$  was produced via the  $^{209}\text{Bi}(\alpha, 2n)^{211}\text{At}$  reaction. The target was set in a quartz column and was heated to 850° C with flowing mixed helium/oxygen gas (3:1) at a rate of 20 ml/min, while the thermo-chromatographic column connected to the distiller had a temperature gradient. Then, the gamma-ray was measured with the detector to determine adsorption position of  $^{211}\text{At}$ . As a result, 3 peaks of  $^{211}\text{At}$  were observed over the temperature range between 100 and -80 °C, which is qualitatively consistent with our previous study. However, the adsorption temperature of the observed peaks was different from that in the previous study. Detail of the results will be presented in the symposium.

#### **1A07 Experimental and computational study of nitrate complex of Zr, Hf, and Th - toward the chemical study on Rf**

WATANABE, E.<sup>1</sup>, HAYAMI, S.<sup>1</sup>, TONAI, K.<sup>1</sup>, NINOMIYA, H.<sup>1</sup>, KASAMATSU, Y.<sup>1</sup>, KITAGAWA, Y.<sup>2</sup>, SHIGEKAWA, Y.<sup>3</sup>, YOKOKITA, T.<sup>3</sup>, NAKANO, M.<sup>2,4</sup>, SHINOHARA, A.<sup>1</sup>  
(<sup>1</sup>Graduate School of Science, Osaka Univ., <sup>2</sup>Graduate School of Engineering Science, Osaka Univ., <sup>3</sup>Nishina Center, RIKEN, <sup>4</sup>Institute for Molecular Science)

We are interested in the chemical properties of element 104, Rf. We aim to conduct anion-exchange experiments of Rf in nitric acid using the automated solid-liquid extraction apparatus for online use (AMBER), and to obtain the distribution coefficients in ion exchange equilibrium. As preliminary experiments, we have previously conducted anion-exchange experiments in nitric acid by a batch method using radioactive tracers of Zr, Hf, and Th, which form tetravalent ions in an aqueous solution same as Rf, and it was found that the ion exchange reaction equilibrium with Adogen 464 resin is rapidly reached. In this presentation, we used the radioactive tracers of Zr, Hf, and Th to optimize the conditions in the extraction using AMBER; for example, the conditions for back extraction from the resin. Furthermore, we tried to identify and understand chemical species present in nitric acid solution by DFT calculation. Analysis of the molecular orbitals of  $[\text{Th}(\text{NO}_3)_6]^{2-}$ , which is stably present in nitric acid, suggested that the 5f orbitals of Th partly participate in the bonding orbital between Th and  $\text{NO}_3^-$ . In addition, it was suggested that Th ion prefers neutral or anion complexes coordinated by 4 or more nitrate ions, while Zr is most stabilized when two nitrate ions are coordinated.

### 1A08 Anion exchange of Rf in H<sub>2</sub>SO<sub>4</sub>

YOKOKITA, T.<sup>1</sup>, KASAMATSU, Y.<sup>2</sup>, WATANABE, E.<sup>2</sup>, KOMORI, Y.<sup>1</sup>, NINOMIYA, H.<sup>2</sup>, WANG, Y.<sup>1</sup>, MORI, D.<sup>1</sup>, GHOSH, K.<sup>1</sup>, SHINOHARA, A.<sup>2</sup>, HABA, H.<sup>1</sup>

(<sup>1</sup>RIKEN, <sup>2</sup>Osaka Univ.)

It is difficult to obtain distribution data at equilibrium for the short-lived <sup>261</sup>Rf in 2-phase distribution, but such data are necessary to discuss in detail the chemical properties of Rf. To obtain distribution coefficients ( $K_d$ ) of Rf, a batch-type solid-liquid extraction apparatus (AMBER) was developed. In this work, to study the sulfate complexation of Rf, we performed an anion-exchange experiment of Rf in H<sub>2</sub>SO<sub>4</sub> by using AMBER.

<sup>261</sup>Rf and <sup>169</sup>Hf were produced in the <sup>248</sup>Cm(<sup>18</sup>O,*xn*)<sup>261</sup>Rf and <sup>nat</sup>Gd(<sup>18</sup>O,*xn*)<sup>169</sup>Hf reactions, respectively, by using the AVF cyclotron at RIKEN. The products were transported from the target chamber to AMBER with a He/KCl gas-jet system. We performed anion-exchange experiments of <sup>261</sup>Rf and <sup>169</sup>Hf by using AMBER. After the anion exchange, we measured  $\alpha$ -particles for the samples by using an automated rapid  $\alpha$ /SF detection system.

We obtained the  $K_d$  value of Rf at 0.1 M H<sub>2</sub>SO<sub>4</sub>. The  $K_d$  value of Rf is clearly lower than those of Zr and Hf and agrees with those of Th. This result suggests that Rf does not form an anionic sulfate complex at 0.1 M H<sub>2</sub>SO<sub>4</sub>, though there is a possibility that a counter ion of HSO<sub>4</sub><sup>-</sup> is preferentially adsorbed on the resin. To clarify the formation of the anionic sulfate complex of Rf in this studied condition, further experiment of Rf is required at low HSO<sub>4</sub><sup>-</sup> concentration.

### 1A09 Coprecipitation experiments of element 102, No, with Sm hydroxide with NH<sub>3</sub> and NaOH aqueous solutions.

HAYAMI, S.<sup>1</sup>, NINOMIYA, H.<sup>1</sup>, WATANABE, E.<sup>1</sup>, SHIGEKAWA, Y.<sup>2</sup>, NAGASE, M.<sup>1</sup>, KASAMATSU, Y.<sup>1</sup>, KONDO, N.<sup>1</sup>, HABA, H.<sup>2</sup>, YOKOKITA, T.<sup>2</sup>, KOMORI, Y.<sup>2</sup>, MORI, D.<sup>2</sup>, WANG, Y.<sup>2</sup>, GHOSH, K.<sup>2</sup>, SATO, N.<sup>2</sup>, SHINOHARA, A.<sup>1</sup>

(<sup>1</sup>Grad. Sch. of Sci., Osaka Univ., <sup>2</sup>RIKEN Nishina center)

Nobelium with atomic number 102 is one of actinide elements. It is reported that stable oxidation state of No is +2 although those of other heavy actinide elements are all +3. The chemical behavior of No is reported to be similar to that of Group 2 elements. However, it is difficult to investigate the chemical properties of No because of the low production rates and short half-lives. In this study, by applying the samarium hydroxide coprecipitation method, we performed online coprecipitation experiment of <sup>255</sup>No using semi-automated coprecipitation equipment. We produced <sup>255</sup>No in the <sup>248</sup>Cm(<sup>12</sup>C, 5n)<sup>255</sup>No reaction with the AVF cyclotron at

RIKEN. We determined the coprecipitation yields of No in dilute or concentrated aqueous  $\text{NH}_3$  or 0.10 or 1.0 M NaOH solutions with the measurement of  $\alpha$ -particles using automatic  $\alpha$ -particle measurement system. As a result, the coprecipitation behavior of No in low hydroxide ion concentration differed from that of Group 2 elements. The No yields in high hydroxide ion concentrations are close to those of Ca.

#### **1A10 Measurement of half-lives and internal-conversion electron energy spectra for U-235m oxide, fluoride, and chloride**

SHIGEKAWA, Y.<sup>1</sup>, KASAMATSU, Y.<sup>2</sup>, YAMAKITA, Y.<sup>3</sup>, KANEKO, Y.<sup>4</sup>, WATANABE, M.<sup>4</sup>, WATANABE, E.<sup>2</sup>, YASUDA, Y.<sup>2</sup>, KONDO, N.<sup>2</sup>, SHINOHARA, A.<sup>2</sup>

(<sup>1</sup>RIKEN Nishina Center, <sup>2</sup>Graduate School of Science, Osaka University, <sup>3</sup>Graduate School of Informatics and Engineering, The University of Electro-Communications, <sup>4</sup>JAEA)

As  $^{235\text{m}}\text{U}$  has extremely low excitation energies, the nucleus interacts with an outer-shell electron in the internal conversion (IC) process. Therefore, the half-life of  $^{235\text{m}}\text{U}$  varies depending on the chemical environment. We have been aiming to elucidate the deexcitation process of  $^{235\text{m}}\text{U}$  by measuring IC electron energy spectra in addition to half-lives for various chemical environments. In this study, half-lives and energy spectra for  $^{235\text{m}}\text{U}$  oxide, fluoride, and chloride were precisely measured using a retarding-field magnetic bottle electron spectrometer.  $^{235\text{m}}\text{U}$  oxide was prepared by collecting  $^{235\text{m}}\text{U}$  ions recoiling out of a  $^{239}\text{Pu}$  source on the surface of a Cu foil;  $^{235\text{m}}\text{U}$  fluoride and chloride were prepared by subjecting  $^{235\text{m}}\text{U}$  collected on the surface of Cu foils to HF gas and HCl gas, respectively. With the help of the magnetic bottle spectrometer, the half-life and energy spectrum for  $^{235\text{m}}\text{U}$  chloride were obtained for the first time, and those for  $^{235\text{m}}\text{U}$  oxide and fluoride were measured with higher S/N and energy resolution than before. The measured energy spectra allowed for estimating molecular orbital diagrams corresponding to the  $^{235\text{m}}\text{U}$  samples. Comparison between the molecular orbitals diagrams and measured half-lives successfully showed that the half-life variation of  $^{235\text{m}}\text{U}$  dominantly originates from 6p orbital variation.

#### **1A11 Observation of the internal conversion electrons emitted from Th-229m through coincidence measurement between beta particles and electrons from Ac-229**

SHIGEKAWA, Y.<sup>1</sup>, KASAMATSU, Y.<sup>2</sup>, WATANABE, E.<sup>2</sup>, YASUDA, Y.<sup>2</sup>, KONDO, N.<sup>2</sup>, HAYAMI, S.<sup>2</sup>, NINOMIYA, H.<sup>2</sup>, HABA, H.<sup>1</sup>, SHINOHARA, A.<sup>2</sup>

(<sup>1</sup>RIKEN Nishina Center, <sup>2</sup>Graduate School of Science, Osaka University)

The excitation energy of  $^{229\text{m}}\text{Th}$  is only around 8 eV; thus, the decay mode and half-life of  $^{229\text{m}}\text{Th}$  are expected to vary depending on chemical environments. The internal conversion (IC) electron of  $^{229\text{m}}\text{Th}$  was recently observed and the half-life of  $^{229\text{m}}\text{Th}$  on the Ni-alloy surface was found to be around 7  $\mu\text{s}$ ; however, half-lives for other chemical environments have not been reported. In order to measure half-lives of  $^{229\text{m}}\text{Th}$  for various chemical environments in the future, we tried to measure IC electrons of  $^{229\text{m}}\text{Th}$  through coincidence measurement between beta particles and electrons from  $^{229}\text{Ac}$ . Due to the low recoil energy in the beta decay of  $^{229}\text{Ac}$ , the chemical environment of  $^{229\text{m}}\text{Th}$  can be controlled by controlling that of  $^{229}\text{Ac}$ . First, we fabricated  $^{229}\text{Ac}$  through proton irradiation of a  $^{232}\text{Th}$  target. Then, we chemically purified  $^{229}\text{Ac}$  and prepared an electrodeposited  $^{229}\text{Ac}$  source. We measured the detection times of beta particles and electrons from the source, and constructed coincidence spectra. The prepared  $^{229}\text{Ac}$  source was found to include only Ac isotopes, showing that the chemical purification process was successfully performed. In a coincidence spectrum, we successfully observed a decay curve (half-life  $10.2 \pm 7.8 \mu\text{s}$ ) corresponding to the IC electrons of  $^{229\text{m}}\text{Th}$ .

#### **1A12 Quantitative evaluation of DNA double strand break caused by radiations with different LET**

WADA, T.<sup>1</sup>, NAKATA, M.<sup>1</sup>, KOIKE, A.<sup>1</sup>, YAMAZAKI, S.<sup>1</sup>, ZHAO, M.<sup>1</sup>, SUN, F.<sup>2</sup>, SHIMOYACHI, H.<sup>3</sup>, HATANO, Y.<sup>3</sup>, KENMOTSU, T.<sup>4</sup>, OYA, Y.<sup>1</sup>

(<sup>1</sup>Graduate School of Integrated Science and Technology, Shizuoka University, <sup>2</sup>Faculty of Science, Shizuoka University, <sup>3</sup>Hydrogen Isotope Research Center, University of Toyama, <sup>4</sup>Faculty of Life and Medical Sciences, Doshisha University)

Since the accident of Fukushima Daiichi nuclear power plant, people are concerned with biological effects by radiation especially damage caused by  $\beta$ -rays from tritium, which contained in polluted water in Fukushima power plant. The radiation effect for DNA is different among various radiations with different linear energy transfer (LET) values. In the present study, the effect of radiation with various LET values on genome-sized DNA double strand breaks (DSBs) was quantitatively evaluated using several types of radiation sources. The DNA of bacteriophage (T4 GT7: 166 kbp) was exposed to various radiation sources ( $^{45}\text{Ca}$ ,  $^{60}\text{Co}$ , etc.) with similar dose level (0.50–25 Gy). After fluorescently dyeing procedures for DNA, the length of DNA molecules was evaluated by single-molecule observation method using fluorescence microscope. A number of DSBs were calculated quantitatively. As a result,  $^{45}\text{Ca}$  caused larger number of DSBs than  $^{60}\text{Co}$ . It is plausible that high concentration of radicals induced by  $\gamma$ -ray ( $^{60}\text{Co}$ ) irradiation enhanced

recombination of radicals, and the recombination led to the suppression of DSBs compared with that of  $\beta$ -ray ( $^{45}\text{Ca}$ ) irradiation. This is because the dose rate of irradiation was quite different between  $^{60}\text{Co}$  (50 Gy/h) and  $^{45}\text{Ca}$  ( $2.0 \times 10^{-2}$  Gy/h). Due to this big difference, a dose rate had stronger influence on DSB rate than LET.

### **1A13 Correlation measurement of precision mass and decay properties of $^{207}\text{Ra}$ with MRTOF + $\alpha$ -TOF.**

NIWASE, T.<sup>1,2,3</sup>, WADA, M.<sup>3</sup>, SCHURY, P.<sup>3</sup>, ITO, Y.<sup>4</sup>, KIMURA, S.<sup>2</sup>, KAJI, D.<sup>2</sup>, ROSENBUSCH, M.<sup>2</sup>, WATANABE, Y. X.<sup>3</sup>, HIRAYAMA, Y.<sup>3</sup>, MIYATAKE, H.<sup>3</sup>, MOON, J. Y.<sup>7</sup>, ISHIYAMA, H.<sup>2</sup>, MORIMOTO, K.<sup>2</sup>, HABA, H.<sup>2</sup>, TANAKA, T.<sup>8</sup>, SHIZAWA, S.<sup>5,23</sup>, TAKAMINE, A.<sup>2</sup>, MORITA, K.<sup>1,2</sup>, WOLLNIK, H.<sup>6</sup>

(<sup>1</sup>Kyushu Univ., <sup>2</sup>RIKEN, Nishina Center, <sup>3</sup>KEK., <sup>4</sup>JAEA., <sup>5</sup>Yamagata Univ., <sup>6</sup>NMSU., <sup>7</sup>IBS., <sup>8</sup>ANU.)

The atomic mass is a unique quantity for each nuclei. Therefore, precision mass measurement allows us to identify the atomic number as well as the mass number of the nuclide. Recently, we developed a novel detector as named “ $\alpha$ -TOF” for precision mass measurement of superheavy nuclei with multi-reflection time-of-flight mass spectrograph(MRTOF-MS). The  $\alpha$ -TOF detector is capable of performing correlation measurement of time-of-flight signal and successive  $\alpha$  decay signal. It can reliably discriminate true events from background events.

The first online experiment of the  $\alpha$ -TOF detector was performed at SHE-Mass-II coupled with the gas-filled recoil ion separator GARIS-II and MRTOF-MS. A short lived radium isotope  $^{207}\text{Ra}$  was produced in the  $^{159}\text{Tb}(^{51}\text{V}, 3n)$  reaction. The reaction products(evaporation residues : ERs) were in-flight separated from the projectiles and some other background products. The ERs was captured and thermalized in a cryogenic gas-cell. The thermalized ions were extracted by using the rf-carpet and transported to MRTOF-MS via multiple ion traps.

As a result of the experiment, the time-of-flight and correlated accompanying decay signals were successfully measured. By correlating with disintegration events, we confirmed that only true events can be distinguished even in high background environments.

### **1A14 Identification of Atomic Number for Heavy Elements by Bragg Curve Measurement**

FUJITA, K., NIWASE, T., SHIRASAKA, K., SUEKAWA, Y., MORITA, K.

(<sup>1</sup>Kyushu Univ., <sup>2</sup>RIKEN Nishina Center)

A direct measurement of the atomic number is demanded for the experiments of the superheavy



nuclei synthesis such as 119th element search, since the conventional method of analyzing the alpha-decay chain have a limitation of identification for spontaneous-fission nuclei. We have developed a Bragg curve detector(BCD) employing a digital signal processing technique to improve the separation efficiency especially for low-energy superheavy ions. Although the height of Bragg peaks induced by heavy ions of less than 1.5 MeV/u are not proportional to the incident energy, the waveform analysis makes it possible to identify the nuclei having the different atomic number.

The performance test of the developed detector was performed at Kyushu University Center for Accelerator and Beam Applied Science. The heavy ion beams supplied from the Tandem accelerator were scattered and injected to the BCD. The measured waveforms of the BCD well matched to the simulation results using Garfield++ with a field map obtained from Gmsh and Elmer. A sufficiently high separation efficiency was achieved at the same energy particles with different atomic number.

**1A15** Development of an atomic beam source using a high-temperature nozzle type cavity for atomic beam generation of superheavy elements

TOMITSUKA, T.<sup>1,2</sup>, SATO, T. K.<sup>1,3</sup>, ITO, Y.<sup>1</sup>, TOKOI, K.<sup>1,3</sup>, SUZUKI, H.<sup>1,3</sup>, ASAI, M.<sup>1</sup>, TSUKADA, K.<sup>1</sup>, GOTO, S.<sup>2</sup>, NAGAME, Y.<sup>1</sup>

(<sup>1</sup>ASRC, JAEA, <sup>2</sup>Graduate School of Science and Technology, Niigata Univ., <sup>3</sup>Graduate School of Science and Engineering, Ibaraki Univ.)

To study atomic properties of superheavy elements, we have been developing an Atomic Beam Source apparatus (ABS) with a high-temperature nozzle type cavity coupled to the He/CdI<sub>2</sub> gas-jet transport system. Configurations of a nozzle-type cavity for effective extraction of thermal atomic beams have been examined using Monte Carlo simulation, and off-line extraction experiments with stable isotopes have been conducted. According to the simulation, large amounts of atomic beams get out of the inlet of the nozzle cavity. Thus, to avoid escaping beams from the inlet, we need to minimize the inlet diameter of the nozzle cavity. Here, we have implemented an aerodynamic lens (AL) to the ABS to reduce the loss of atomic beams from the inlet of the cavity. The AL consists of three lens orifices and four spacers, so that the aerosol particles converge in the lens axis by passing through lens orifices, which can produce a narrow aerosol flow. In this work, injection efficiencies of the gas-jet transported materials into the ABS nozzle were measured as a function of a flow rate of the carrier gas using fission products of <sup>252</sup>Cf and short-lived nuclides synthesized in nuclear reactions. The details of the experiments and

results will be discussed at the presentation.

**1A16 Development of an ion-electron recombination atomic beam source for atomic beam spectroscopy of superheavy elements**

SUZUKI, H.<sup>1,2</sup>, ITO, Y.<sup>2</sup>, SATO, T.<sup>1,2</sup>, TOMITSUKA, T.<sup>2,3</sup>, TOKOI, K.<sup>1,2</sup>, TSUKADA, K.<sup>2</sup>, ASAI, M.<sup>2</sup>, NAGAME, Y.<sup>2</sup>.

(<sup>1</sup>Graduate school of science and engineering, Ibaraki Univ., <sup>2</sup>ASRC JAEA, <sup>3</sup> Graduate school of science and technology, Niigata Univ.)

In the heavy element region, there is a possibility of violation of periodicity on electronic structure of an atom by the influence of the relativistic effect. Especially, focusing on the ground-state electronic configuration of Lr ( $Z = 103$ ), the valence electron orbital takes  $7p_{1/2}$  rather than  $6d_{3/2}$  assumed from the periodic rule. Our group has succeeded in measuring the first ionization potential of Lr in recent years and obtained a strong support for the  $7p_{1/2}$ .

In this work, we have developed an ion-electron recombination atomic beam source for atomic beam spectroscopy for direct determination of valence electron structures of superheavy element atoms. An ion-electron recombination has an advantage of producing a low-energy atomic beam without chemical dependences, while their recombination cross sections are so small. To overcome the drawback, an electron focusing system “e-Neutra” has been implemented in the apparatus, where the ion beam focused and adjusted by an einzel lens and steerers is injected into the center of a high-density electron cloud. As a result, a low-energy atomic beam is efficiently produced by recombining with the electrons.

In the presentation, we will report on the experimental results and the details of the improved ion-beam optics and the future prospects.

**1B01 Relationship between radioactive cesium concentration and soil properties in depth-sorted soil collected in Kawasaki, Japan**

TAKAHASHI, T.<sup>1</sup>, ICHIHASHI, M.<sup>1</sup>, SAKANO, K.<sup>2</sup>, KOIKE, Y.<sup>2</sup>

(<sup>1</sup>Grad. Sch. of Sci. and Tech., Meiji Univ., <sup>2</sup>Sch. of Sci. and Tech., Meiji Univ.)

Radioactive cesium was detected in soils sampled at Kawasaki, Japan. Estimating the speciation of radioactive cesium in soil is important for future migration studies. In this study, radioactive cesium concentration and soil properties in depth-sorted soil were analyzed for predicting the long term effect at observation site. The highest concentration of  $^{137}\text{Cs}$  was observed at a depth of 5 to 10 cm. In addition, the water content and the organic material content

showed an inverse correlation with  $^{137}\text{Cs}$  concentration. As a result of the sequential extraction test, the chemical form of  $^{137}\text{Cs}$  was different from the surface layer of the soil and the soil deeper than 10 cm in depth.  $^{137}\text{Cs}$  in the surface soil was present in an almost insoluble form. On the other hands, water soluble  $^{137}\text{Cs}$  was observed only in the soil at a depth of 10 to 20 cm. From the sequential extraction method and soil property analysis, the activity distribution of  $^{137}\text{Cs}$  showed different behavior at each depth of soil. The secondary transfer of radioactive cesium in soil over time was evaluated by combining depth profile analysis of  $^{137}\text{Cs}$  in soil with soil property analysis.