Date: December 16, 2014
Global Relations and Research Coordination Office RIKEN

Research Project Mid-term Evaluation Result

The following research project underwent a mid-term evaluation in accordance to Clause 10 and 11, Chapter 2 of the *Regulations for Research and Development Evaluations* (Regulation No. 74, October 1, 2003.)

Evaluation system:
Two experts from outside of RIKEN and three RIKEN Science Council Research Programs Committee members were appointed as reviewers for the following research project. The reviewers evaluated the project based on the reporting session held on October 29, 2014.

Reviewers list:

External experts (alphabetical order)

1) Ryugo HAYANO, The University of Tokyo
2) Yasuhiko KOBAYASHI, Medical and Biotechnological Application Unit
   Quantum Beam Science Center (Takasaki) ,Japan Atomic Energy Agency, Japan

RIKEN Science Council Research Program committee member(alphabetical order)

3) Kimitoshi KOHNO, Chief Scientist, Low Temperature Physics Laboratory
4) Tetsuo HATSUDA Chief Scientist, Quantum Hadron Physics Laboratory,
   RIKEN Nishina Center for Accelerator-Based Science
5) Takashi TANAKA , Chief Scientist,
   Innovative Light Sources Division Advanced X-Ray Laser Laboratory,
   SPring-8 Center

Research project brief overview

Project name: Pursing a new science field using extreme particle beams
Project Leader： Toshiyuki Azuma
Project duration： April, 2011～March, 2016（5 years）
Budget allocated：Total of 677,300 thousand Yen（4 years）
Research overview：

Control of particle beams is now in the phase of change owing to the dramatic progress of technological aspects, and pursuing new science field contributing diverse research fields of chemistry, material science, biology, and space science. In the framework of the present Basic Science Interdisciplinary Research Projects, the group aim to develop a variety of particle beam researches based on brand new three idea, namely quantum-state controlled macro-molecular ion beam, magnetic microscope by muon beam with resolution of micron, and living cell surgery by micro ion beam.

1. Comprehensive Evaluation (To be disclosed)

1) Evaluation on five-grade scale	S	A	B	C	D
(1) Research objective:	2	3	0	0	0
(2) Implementation of research plan:	2	2	1	0	0
(3) Research achievement:	2	3	0	0	0
(4) Future research plan:	2	2	1	0	0

S Outstanding / A Excellent / B Good / C Acceptable / D Not acceptable

2) Evaluation details (reviewer's number is different from the order of the above list)

＜Reviewer 1＞

(1) "Pursuing New Science Field Using Extreme Particle Beams" research project led by Dr. Azuma is aimed to develop a variety of new particle beam researches. In order to accomplish this aim, three new ideas are introduced, that is, 1: "quantum-state controlled macro-molecular ion beam," 2: "magnetic microscope by muon beam with one-micron resolution," and 3: "living cell surgery by micron ion beam". All the three ideas are brand-new and highly motivated. It is to challenge a risky research subject that is the RIKEN spirit. In particular, the first subject carried out by Sub-group1 (Leader: Dr. T. Azuma) is to develop a tabletop cryogenic electrostatic storage ring to study low-energy collision dynamics between heavy and complex ions and neutral atoms. Such conditions have never been achieved and it may emerge a new knowledge on the understanding of formation of bio-molecules in interstellar space. The second topic carried out by Sub-group2 (Leader Dr. M. Iwasaki) is a part of large project to produce an ultra-slow muon beam to study μSR with a micrometer resolution. Such a muon beam can be produced by laser dissociation of a thermalized muonium, which is a bound state between a positive muon and electron. To produce a sufficiently-high thermalized-muonium flux, surface structured aerogel is proposed as a target material which is irradiated by a muon beam. The aim of this sub-group within this project is to develop the structured aerogel and achieve a high efficiency in muonium production. The third topic, living cell surgery, is studied by Sub-group3 (Leader: Dr. Y. Yamazaki). An ion beam from a Pelletron accelerator is focused to irradiate a particular part of single cell, by using a tapered glass capillary of which the end is sealed. By adjusting the lateral position of capillary end and ion beam energy, the irradiation position can be specified in 3D coordinate with a few microns resolution. By employing this technique, irradiation effect to a live cell is to be studied. Such a knowledge is not available while it is essential for the understanding and medical treatment of radiation exposure. The aims of all the three research topics are not only very curious from a fundamental-science view point but also important to solve social challenges. They are excellent.

(2) All the research works for the three topics have been carried out along with well-designed

plans and under appropriate supervisions. In particular, the development of the tabletop cryogenic electrostatic storage ring has an aspect of highly challenging technical R&D. Therefore, without a superior supervision, one cannot expect a success.

(3) The development of tabletop cryogenic electrostatic storage ring has been carried out very successfully and Sub-group1 has finished the construction of the storage ring. Ne^+ ions are stored in the ring successfully in July 2014. Cooling accelerator is a real challenge because thermal contraction of different materials may result unpredictable misalignment of the apparatus. The Sub-group1 succeeded in cooling the accelerator down to 4.7 K and achieved ion storage. It is a *tour de force* apparatus in the World. Sub-group2 succeeded in producing a high intensity muonium flux. The sub-group obtained about 3% muonium yield of stopped muon in aerogel. This value is one order of magnitude higher than the previous result. And it is highly promising to produce a sufficient ultra-slow muon beam after laser dissociation. The sub-group carried out the research and development of a laser system to produce VUV light for the laser dissociation of muonium, in parallel to the present sub-project. That project is supported by a different grant, but closely related to the present project. A new Nd:YGAG crystal was successfully synthesized. With this crystal one can first realize a light source to excite Kr atom to produce Lyman-α (~122 nm). Sub-group3 performed an irradiation of living-cell nucleus to see a radiation effect. By use of green fluorescent protein (GFP) in the nucleus, they succeeded to observe a slow development of bleaching of GFP signal after ion irradiation in both intensity and size. The time constant of this development was found 26 s. This slow bleaching development was only observed in live cells, but not in fixed and dead cells. Since the experimental technique is quite new, various other interesting trials have been made, and a lot of new knowledge is coming out. The central aims of this project are research and development of new apparatus and methods and they are successfully achieved expected goals of the project.

(4) Because the main goal of this project is research and development of new apparatus and methods, the next goal or future plan is to use the developed apparatus or methods to study scientific subjects. It is very straightforward. Since the developed apparatus and methods are new and state –of-the-art, it is highly promising to find exciting results. The outcome of this project will expand our frontiers of knowledge in a significant way.

＜Reviewer 2＞

The aim of this research project, Pursuing a new science field using extreme particle beams, is appropriate from the perspective of basic science interdisciplinary research. Three sub-groups and their research contents are well organized and balanced. All these three new idea, namely quantum-state controlled macro-molecular ion beams, magnetic microscope by muon beams with resolution of micron, and living cell surgery by energetic charged particle microbeams, are excellent.

Based on these newly developed devices, an interdisciplinary field bridging quantum beam technology and interdisciplinary science including chemistry and biology will be opened in the next step of this project. Especially, the application of localized radiation to a targeted region of a sample using microbeams allows for the precise investigation of hit effects on individual cells within a population. Another advantage associated with the use of microbeam irradiation concerns the precise detection of hit position on micron-scale targets. Moreover, the use of microbeams allows for investigation of the mechanisms underpinning radiation-induced bystander effects, which include responses such as gene mutations, chromosome aberrations and cell death. The use of microbeams is not restricted to the area of radiation biology and can be applied to other areas including its use as a micro-radiosurgical tool to target specific tissue regions of biological samples. Microbeams can inactivate specific cell populations in multicellular organisms by targeted irradiation and allow for the investigation of their function by observing changes in the irradiated targets.

Major results of this project are basically development of new particle beam techniques. These technological achievements are undoubtedly great and important, however, from the perspective of science, new physics and experiments are unfinished except the single cell irradiation experiments. Therefore it is strongly recommended to proceed towards the next step of this project. Future plans for the next two years are reasonable and significant achievements are expected.

＜Reviewer 3＞

(1) Research objective

The research objectives using the three different kinds of particle beams proposed by individual subgroups are quite challenging and attractive, and thus the research project has a potential to pioneer a new field of science using these “extreme” beams. To my knowledge, their concepts and technologies are unique and original, or at least emerging, and thus are highly evaluated.

(2, 3) Implementation of research plan & Research achievement

The achievements made by the subgroups are satisfactory. The cryogenic electrostatic ion storage ring (RICE), which was developed by the subgroup1 headed by Dr. Azuma, has become the first successful device among competitive ones in the world. The high-yield generation of ultra-slow muonium and its ionization, which was achieved by the subgroup2 headed by Dr. Iwasaki, will eventually lead to the application of the muon beam as a new magnetic probe. The ion micro-beam produced with the tapered glass capillary, implemented by the subgroup3 headed by Dr. Yamazaki, has already revealed a number of new phenomena in cell biology. Although the research activities of each subgroup seem rather independent, the achievements made so far, together with the implementation of research plan which realized the above successful results, are highly evaluated.

(4) Future research plan

The research plan explained by the subgroups are reasonably well organized. The subgroup1 is aiming at further improvement of RICE to achieve the beam performance as designed and will soon start experiments, which probably may be performed only by RICE. The subgroup2 will extend their results to actually applying their concept to real applications using the muon beam. The subgroup3, which has now established the technology of ion micro-beam irradiation, will further push forward their researches. We can expect interesting and emerging results from the advancements of their researches. In terms of the future possibility of the research project, however, it is not very clear to me how individual research objectives will grow up to something new in a synergetic manner. It is appreciated if the subgroup leaders try to explore new potential applications of their concepts and technologies, so that this research project can lead to a new and core activity of RIKEN.

＜Reviewer 4＞

The main purpose of this project is to form an interdisciplinary platform with the extreme particle beams as a common technology. Taking advantage of the diversity of particle beams (molecules, muons, ions) and their broad applications (chemistry, astrophysics, condensed matter, biology), the project aims at not only exchanging scientific and technological ideas but also nurturing young researchers.

This project is composed of three subgroups:

・The major achievement of subgroup 1 (cold molecular physics using cryogenic electrostatic ion storage ring) is the completion of RICE (RIken Cryogenic Electrostatic ion storage ring) and its successful operation for ion storage on July 2014. This opens new experimental possibilities to study the atomic/molecular interactions at extreme low temperature and density realized only in interstellar environments.

・The major achievement of subgroup 2 (Ultra-slow muon beam for muon microscopes) is the order of magnitude enhancement of the low-energy muonium production by using the laser-ablated silica-aerogel target. This together with the new laser crystal (Nd:YGAG) would produce ultra-slow muons which can be used for the studies of particle physics and condense matter physics.

・The major achievement of subgroup 3 (single cell irradiation of high-energy ion beam) is the successful preparation of the ion beam with tapered glass capillary as well as the development of single ion counting technique. This makes the cell-by-cell irradiation possible and would open a new field of micro-radiation biology.

In all three subgroups, the researchers inside and outside of RIKEN are actively participated. In particular, 10 young researchers from Japan and from abroad join one of the subgroups and play key roles/contributions.

At present, subgroups 1 and 2 are more or less ready to conduct real applications: I am looking forward to seeing some (preliminary) results before the end of this project on March 2016. In particular, experiments on very slow ion-neutral collisions using RICE in subgroup-1 would be very important and has high impact in the field of molecular and astrophysical sciences. Subgroup 3 has already started applications to the dynamic behavior of bleaching, cell cycle monitoring and radiation resistance of cell motors, although mechanisms of the responses under irradiation are yet unsolved.

I have two recommendations which could make this project even more successful.

1. Although the achievements of individual subgroups are impressive, more coherent attempts would be important to exchange ideas among subgroups. Joint meetings on a daily (or weekly or monthly) basis organized by subproject leaders or by postdocs would be useful.
2. It would be a nice idea in subgroup-1 to seek for intensive collaboration(s) with theorists inside and outside of RIKEN who are working on atomic and molecular interactions/reactions. Since there are remarkable progresses in theoretical techniques and computational powers, collaboration(s) with theorists would be quite beneficial for subgroup-1 not only to analyze their data but also to set future directions to be explored by RICE.

＜Reviewer 5＞

(1) Research objective

The research project “Pursuing new science field using extreme particle beams” lead by Dr. Azuma, conducted within the framework of “basic science interdisciplinary research projects” of RIKEN, comprises three subgroups, 1) cryogenic electrostatic ion storage ring (called RICE), 2) muonium production, and 3) single-cell irradiation. Of these, subgroup 1 has so far been allocated about three quarters of the total budget (246,400 kYen out of 332,400 kYen), and thus is the most important of the subgroups. In fact, this project would not have started without the initiative and enthusiasm of Dr. Azuma, who already successfully constructed an electrostatic storage ring at TMU, before he assumed the present position at RIKEN, and strived to realize a cryogenic electrostatic ring at RIKEN.

Unlike the conventional cooler rings based on magnetic optics, an electrostatic storage ring can store ions regardless of their masses, making it an interesting tool for studying complex molecular ions. By cooling the whole ring to cryogenic temperatures as in the case of RICE, the internal degrees of freedom of the stored ions can be “frozen”. This makes it possible to study ion structures in detail, or to perform ion-molecule collision experiments at very low energies. Such studies are important in understanding, e.g., the molecular evolutions in the universe.

It is worth mentioning that being a (relatively high risk) construction project, it would have been difficult for the RICE project to take off using external competitive funding sources, such as the grants-in-aid of JSPS/MEXT.

(2) Implementation of research plan

The design of the RICE ring was started in 2010, before the present funding period, and therefore the team was well prepared already at the start of the project. This does not mean the project was easy. There were many (unforeseen) obstacles which the team had to overcome, and various accelerator/cryogenics expertise available at RIKEN was helpful to the project. Subgroups 2 & 3 also made good progress in this period, but the synergy between the three subgroups appears to be minimal.

The understanding of the present reviewer is that the present project would have been meaningful if proposed by the subgroup 1 alone, but the RIKEN rules for the "interdisciplinary projects" required the inclusion of several subgroups. The present reviewer therefore does not consider the lack of synergy to be a flaw, and only evaluates the progress of subgroup 1.

(3) Research achievement

In 2014, 15 keV Ne^+ ions were successfully stored in the RICE ring. The ring was cooled to a temperature of <4.7 K, and had a high vacuum (estimated to be better than 10^{-12} torr). This is a significant milestone of the project, and is to be much congratulated.

(4) Future research plan

The experimental results obtained using the RICE ring are yet to come. The physics papers of subgroup 1 listed in the progress report, such as the experiment on methylene blue (MB), were obtained by using the room-temperature ring at TMU. Having completed the construction of RICE, the team can now extend the studies they have so far done at room temperature to the liquid-helium temperature. Experiments in which the cold ions are merged with co-moving neutral atoms and with a laser beam are being planned.

The RICE is not without competitions. There are two other cryogenic electrostatic rings in the world, DESIREE at Stockholm and CSR at Heidelberg, each pursuing similar but slightly different goals. Now that the construction phase of RICE is over, the eventual success of the project depends on the ingenuity of the RICE team to choose interesting/important research projects.

RIKEN Science Council Research Programs Committee