平成 28 年 3 月 24 日

国立研究開発法人理化学研究所
理事　松本洋一郎

平成 27 年度実施 主任研究員の研究業績レビュー（中間）の結果について

主任研究員制度設置規程(平成 25 年規程第 13 号)第 5 条に基づき主任研究員の研究レビュー（中間）を踏まえ、レビューアーから送られた評価結果は以下のとおりです。

１．評価対象：加速器基盤研究部上垣外 修一　主任研究員

１）評価体制

実施日：平成 28 年 1 月 12 日（水曜日）
4 名の所外有識者を評価委員とするヒアリングレビューを実施。
評価者：
Luciano CALABRETTA, Dr.
Laboratori Nazionali del Sud, Istituto Nazionale di Fisica Nucleare

Kichiji HATANAKA, Professor
Research Center for Nuclear Physics, Osaka University

Yoshiharu MORI, Professor
Kyoto University Research Reactor Institute

Katsunobu OIDE, Professor
High Energy Accelerator Research Organization

２）評価結果の概要等

General comments:

【Reviewer 1】

The primary objective of the Accelerator Group (AG), lead by the Chief Scientist Osamu Kamigaito, has been the operation and development of the RIKEN RIBF, since shortly after its construction in 2006. The AG had to operate the facility to provide various heavy ion beams to a number of experiments for the nuclear/material/biological/medical sciences, and the challenge was how to maximize the beam performance of the world-leading facility. Indeed the AG achieved this goal by successfully increasing the beam intensity to 50 pnA for the most-difficult U beam in 2015. In the case of lighter nuclei such as He, N, O, Ca, etc., they went beyond 100 pnA much earlier, and reached the design intensity 1,000 pnA for d, He, and N by 2010. As for the U beam, they invented novel schemes for the charge stripping, He gas and Highly oriented graphite targets, which were innovative keys of the intensity boost since 2011. Now the RIBF enjoys the top runner in the field of heavy-ion facility with a lead of more than 2 orders high in the intensity of the U beam.

The achievement of the high intensity beam operation was also the result of continuous efforts to maintain and improve the entire facility, which has a number of aged parts in the injectors and cyclotrons. A new injector complex RILAC2 was constructed in this period with SC-ECRIS ion source, a new RFQ and DTL accelerators. Various new techniques were also

developed for stabilization, beam diagnostics and control. The resulting beam availability becomes higher than 90%, a level of large scale accelerator facilities in the world, since 2013. It must be noted that the AG performed these tasks with a relatively very small number of staff compared to the size of the facility.

Cyclotron is the heart of RIKEN. The success of the RIBF by the Accelerator Group has surely opened the new era of RIKEN cyclotron. There is no doubt that RIKEN continues to be the leader in this field, as the needs for the nuclear science using this facility will expand more and more in coming decades, that is why other countries such as US, Germany, Korea are constructing new facilities. The top runner cannot quit the race in the middle. The RIBF must achieve at least 1,000 pnA of the U beam in the coming years, and fully extract the potential of this wonderful facility.

【Reviewer 2】

Radio Isotope Beam Facility (RIBF) in RIKEN is one of the major accelerator facilities of nuclear science in the world. The facility is composed of a complex of accelerators based mainly on cyclotrons and provides high energy heavy ion beams up to uranium. Dr. Kamigaito as Chief Scientist manages and organizes the accelerator group of this facility. We have heard from him on the improvement of accelerator complex characteristics and beam performance since he took up his position in 2008.

One of the most impressive subjects was the beam intensity evolution and beam quality upgrade of uranium ions where the beam current increased almost two orders of magnitude up to more than 45pnA. To achieve this, there were two major improvements; stabilization of rf system for beam acceleration and charge stripping efficiency. The latter was the most difficult bottleneck of beam intensity and availability. Dr. Kamigaito and his group overcame this problem by the invention of a gaseous charge stripping system. Charge equilibrium after stripping is determined by the balance of electron stripping and capture. In the case of helium gas, they found, the capture cross section was rather small, contrary to ordinary considerations, and a highly charged state uranium ion beam could be generated. They invented a new helium gas stripper with an efficient differential pumping system and improved the beam performance dramatically.

Dr. Kamigaito has led his team well to achieve these fruitful results. His strong leadership is also supported and appreciated by his colleagues whom we, reviewers, interviewed separately. I am very impressed by his leadership playing on these establishments of accelerator developments. I believe that his ability as a group leader should be greatly appreciated.

【Reviewer 3】

Main research subject of the accelerator group directed by the Chief Scientist, Osamu Kamigaito is to accelerate high intensity beams to produce radioactive isotope (RI) beams at RIBF. Accelerated ions are in a wide range from H to U. RIBF is one of the world largest RI beam facilities and the target intensity is 1,000 pnA at 400 MeV/u. This is the world highest intensity of U beam. They also provide high intensity beams at a several MeV/u for super heavy element (SHE) search, and beams in a wide energy range for biological applications, RI production for medical use, etc. The stable operation of accelerators is indispensable for users.[

They have achieved the target intensity of 1,000 pnA for He and O beams, 500 pnA for Kr beam and 49 pnA for U beam. These successful achievements are results of their R&D efforts on ECR ion sources, the RF system of RILAC, charge strippers and so on. A new injector consisting of the 28 GHz SC-ECR ion source and RILAC2 was completed on schedule and has been successfully improved and operated. Reviewers appreciate their achievements to upgrade the operational stability as well as the beam intensity. The beam availability has been improved from 70 % in 2008 to 90 % or better in 2015. The helium gas stripper is a remarkable innovation which will be applied in RI beam facilities worldwide.

Reviewers met group members and understood the accelerator group is well managed by the director. Young scientists like postdoctoral fellows are expected to be added in future. Collaboration with universities is important for this purpose.

R&D are planned to further increase the beam intensity and availability. The replacement of dated components is an urgent issue. Especially the plan concerning the RRC is recommended to be established as early as possible. Development of the second charge stripper is another important subject.

They are proposing the RIBF upgrade program to achieve 1,000 pnA U beam. The RIBF is competitive in the world even after the FRIB is commissioned in the USA. The program should be acknowledged by user communities of wide fields.

【Reviewer 4】

The **Research & development objectives** of the Accelerator Group are mainly focused to increase the beam current of the heaviest ions up to a goal current of 1 pμA. This goal joint with the maximum energy achievable for these beams made the RIKEN radioisotope beam facility a world top class facility. Up to now this result has not yet been achieved nowhere in the world and it is a very important goal for itself and mainly for the perspective to produce very high intense and very neutron reach Radioactive Ion Beam by fragmentation of Uranium nuclei. The technological solutions proposed by RIKEN Accelerator Group are a **novelty** and have mainly developed just by the accelerator group. Up to now this approach has permitted to achieve **excellent** results in terms of beam energy and beam intensity delivered to the users.

Few examples of the world class technological instrument developed by the group are:

- The Superconducting ECR Ion Source at 28 GHz, with the **technical innovation** to use a broad “B-minimum” region, that has permitted to deliver Uranium beam with charge state of 35+ and intensity of about 200 μA;
- A **novel** Helium gas stripper is very compact and able to work with very high intensity beam current of Uranium beam and with good stability and uniform thickness. This is a really **unique device at world** that probably will be implemented also in other laboratories;
- The construction of a superconducting Linac will allow the development of the necessary technology and of the know-how that is mandatory for the future development of the facility.

The Accelerator Group led by Osamu Kamigaito has done a huge effort in term of maintenance of the many old subsystem despite the reduction of the funds and some shortage of personnel in some group. Moreover it is impressive the improvement of performance and reliability achieved in the latest 7 years.

The program to increase the reliability of the accelerators is mandatory for the near future. The problem of turn over and of permanent staff reduction could become very serious in the next five years. Moreover the reduction of the funds is a serious problem to renew the old subsystem and for the future research and development plan.

In particular the development plan of the accelerators is a natural development of the previous effort, it is realistic, and could allow maintaining the world leadership of RIKEN in the R.I. beam production if it will start in the near future.

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