平成 24 年 7 月

平成 23 年度 研究業績レビュー（中間レビュー）の実施について

基礎基盤研究推進部
加速器推進課

基幹研究所、仁科加速器研究センター及び放射光科学総合研究センター研究業績レビュー規程（平成 15 年規程第 75 号）に基づき、下記のとおり研究業績レビュー（中間レビュー）を実施いたしましたので報告いたします。

１．森田超重元素研究室（森田浩介准主任研究員）

１）評価体制

実施日：平成 24 年 2 月 29 日（水）
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【アルファベット順】

Kouichi HAGINO	Graduate School of Science, Tohoku University
Sigurd HOFMANN	GSI Helmholtzzentrum für Schwerionenforschung
Hiroari MIYATAKE	Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization, KEK
Hiromichi NAKAHARA	Tokyo Metropolitan University

２）評価結果の概要等（下記評価者順は評価者一覧の順とは異なる）

General comments:

【Reviewer A】

The super heavy element (SHE) laboratory has been established after the success in synthesizing the nucleus of element 113, which is based on the irreplaceable and continuous efforts of the group of Dr. Kosuke Morita and collaborators. Through the long history of the group, I believe the present group has played a leading role for promoting the scientific activities in the field over the world.

Research objectives:

The research region of the super heavy elements opens a new realm of the basic science in nuclear physics and chemistry. Exploring these elements, especially the discovery of new elements at laboratory, would be considered as one of social dreams. In the nuclear physics point of view, these elements will give not only the precise information on the nuclear stability mechanism in many nucleonic systems, but also the reaction dynamics of relevant nucleons of colliding heavy nuclei. In the nuclear chemistry point of view, we expect to find new chemical properties of these elements, which are supposed to be different from the homologues in the periodic table.

This laboratory has taken important roles for extending the scientific research and gives a social impact by discovering a new element. Subjects are classified as (1) searching for the new super heavy elements, (2) spectroscopic study of the heaviest nuclei, (3) study of the chemical properties of the heaviest elements, and (4) study of the reaction mechanism of the fusion process.

Research results:

First of all, it should be noted that a unique combination of the GARIS with a high collection efficiency and the intense heavy-ion beams from the RILAC makes it possible to study rare reaction events attributed to the discovery of a SHE. Especially, a long period of experiment is indispensable in this kind of research. That is realized by the research strategy of the Nishina Center for Accelerator-Based Science.

During the five years research period, the laboratory lead by Dr. Morita has yielded numerous and valuable scientific results by making full use of the GARIS facility. Especially the laboratory has succeeded for exploring the nuclear chemistry in the SHE region by constructing the gas-jet transport systems and the GARIS II (subject (3)).

In the subject (1), the long experimental effort has been paid to confirm the element 113. Through the experiments, the decay scheme from the element 113 observed in the previous past experiments has been confirmed through the decay measurement of 266Bh. Some theoretical works have been also devoted to the mechanism of the SHE synthesis (subject (4)). Moreover they have succeeded the confirmation of the production cross-section of 277Cn and the decay spectroscopy of heavy isotopes 263-265Hs in the subject (2).

It is noted there has been many student trainees supervised and educated by the group members for these subjects.

Management of the Laboratory:

The laboratory has been well organized with limited human resource including the researchers and technicians to perform the above subjects; some of them are highly dedicated to the long machine time for several months. Even though these subjects have been well studied under the collaboration with the domestic and the foreign researchers, the group members seem to have little time for discussion and/or interaction to each other, due to a lot of development works, preparations, and maintenances. Additional research staffs in nuclear physics will make a time for enough researchers interaction to forward effectively the scientific activities.

Future research plans:

An extension of the research to the region of unknown elements and a challenge for the direct mass measurement with MR-TOF device are reasonable future plans, since the performance of the GARIS facility has a potential for taking the leaderships in these subjects among the competitive laboratories in the world. The continuous interaction between the experiments and theories on the heavy element region is highly desirable.

The research plan of the chemistry will open up a frontier in the SHE region with full use of the two experimental set-ups at GARIS and AVF facilities, which will also give a good opportunity for researchers and students in this field. As one of core laboratories of the SHE nuclear chemistry, more strong collaboration with domestic research groups should be encouraged.

Overall assessment:

Thanks for the good research environment, this group has succeeded to perform the scientific research and to enlarge the feasibility during the first five years. It has demonstrated enough scientific abilities of this group, in spite of the limited human resource. The newly constructed equipment's, which are the gas-jet transport systems for the nuclear chemistry and the GARIS II dedicated for the efficient collection of residues from the hot-fusion reactions, will play important roles in future's research plans.

【Reviewer B】

The one day review, taking place at the Superheavy Element Laboratory on February 29, 2012, was well organized. All necessary documents were handed out to the reviewers in advance or during the session.

, I would like to express that I felt very honored for being invited as a reviewer on this important subject, and I would like to thank the Director Dr. Hideto En'yo, the Deputy Director Dr. Walter Henning and the Associate Chief Scientist Dr. Kosuke Morita for their warm hospitality and the open and scientific atmosphere during the sessions. I also would like to thank my co-reviewers for the fruitful and beneficial exchange of ideas.

The research work performed at RIKEN during recent years and the plans for the future were presented in detail in a comprehensive report by Dr. Morita. Four members of the group, who are responsible for different tasks, were interviewed in shorter sessions.

Research objectives of the Superheavy Element Laboratory are focused on the synthesis, identification and study of the stability of the heaviest nuclei and of the chemical properties of the heaviest elements. Since many decades this subject is in the center of interest at major laboratories worldwide. New discoveries belong to the most sensational reports in scientific journals, but not only there, they are also topic news in daily newspapers, radio and television. In this sense, the objectives of the research program, which could culminate in the naming of a new element, would be a major event for the whole laboratory and the whole country.

The main research instrument used by Dr. Morita's group for physical and chemical experiments is the gas-filled separator GARIS and related sophisticated target and detector equipment. This device belongs to the most powerful separators worldwide. After movement of GARIS to the RILAC facility in 2000, a series of important experiments was started. Known data on cold fusion reactions up to the synthesis of element copernicium (Z=112) were confirmed demonstrating the excellent performance of the apparatus. These positive results encouraged the group to start an experiment searching for the new element 113 in the cold fusion reaction ^{70}Zn + ^{209}Bi. Two new decay chains were measured in July 2004 and April 2005. The chains were assigned to the new isotope $^{278}113$.

Correct assignment of the chains was confirmed in a study of the grand-grand-daughter of $^{278}113$, ^{266}Bh, using the hot fusion reaction ^{23}Na + ^{248}Cm. The measured decay data from the observation of 24 decay chains of ^{266}Bh were in agreement with the data measured in the decay chain of $^{278}113$. These data are now ready for being evaluated by IUPAC concerning the priority of discovery of element 113.

Additional experiments are related to the synthesis of new nuclei and decay spectroscopy. These studies can be performed at higher cross-sections and shorter measuring times and are, therefore, extremely valuable for the scientific education of younger people. The same argument holds for the chemical experiments giving young chemists an opportunity to make their diploma or thesis works on a subject of great scientific interest. These experiments are also necessary for testing technical improvements, which is not possible in studies of reactions having low cross-sections.

Several technical developments were conducted, among which the construction of the new separator GARIS-II is the most complex one. The higher efficiency of this separator together with the development of efficient gas transport systems will give access to the study of physical and chemical properties of isotopes and elements, which are not reachable otherwise.

The performed upgrades are necessary prerequisites for the conduction of experiments planned for the future. Continuation of cold fusion using a ^{76}Ge beam and of hot fusion using a ^{248}Cm target are certainly the most important and most challenging studies. Especially the experiments with the ^{248}Cm target open a possibility to synthesize the new elements 119 and 120.

Experimental data obtained by Morita's group are of great interest for theoreticians in various laboratories worldwide, concerning both the stability of SHE and also their synthesis. One paper explicitly mentioned was published by T. Ichikawa and A. Iwamoto dealing with various de-excitation channels of the cold fusion reaction $^{70}Zn + {}^{209}Bi$. Here I would like to encourage the group to continue and to intensify discussions with theoreticians of various laboratories.

From the presented results, the discussions and the laboratory tour I got the impression that the research program is well thought out. It is in line with present technical possibilities and the available man power. Of great advantage compared to other laboratories is the accessibility of long beam times for experiments at low cross-sections. Except at JINR in Dubna this situation is unique worldwide.

The new elements 119 and 120 are probably the last elements which can be produced with present experimental technology. This situation demands special efforts. All premises, long living ^{248}Cm targets, ^{54}Cr beams, except the not yet available ^{51}V beam, and sufficiently long beam times are given at RIKEN and the Superheavy Element Laboratory. Therefore, I suggest pursuing this ambitious aim with high priority. Close collaboration with other laboratories, as it was envisaged in Dr. Morita's program for the future, will certainly be helpful, as it was pointed out in the list of plans for the future.

【Reviewer C】

One of the most important motivations to synthesize and identify new elements is to deepen our understanding of the structure of heavy nuclei and eventually achieve the predicted shell closure around $Z = 120$. These studies have been carried out by using two different types of heavy-ion fusion reactions, that is, the so called cold fusion and hot fusion reactions. The Associate Chief Scientist, Dr. Morita, and his team have been making great efforts, under the strong leadership of Dr. Morita, in this direction using the cold fusion reactions, after the successful discovery of the element $Z = 113$ by Dr. Morita himself and his collaborators. Although it has been unfortunate that they have not yet observed the third event despite their continuous efforts over the past 8 years, they have received world-wide recognition with many invited presentations at international symposiums. Dr. Morita has now been one of the world leaders in this field. In addition, Dr. Morita and his team have also extended their research interests to chemistry studies of superheavy elements (SHE). In fact, the chemistry programs make one of the main future plans of the laboratory, and will be further explored with collaborations with many other universities and institutions outside RIKEN, such as Niigata University, Osaka University, JAEA, Kanazawa University, and Oslo University.

Given that many laboratories in the world have shifted to a SHE research with hot fusion reactions, RIKEN is almost a unique facility at which a SHE search has been carried out with cold fusion reactions, which provide a cleaner identification of elements compared to hot fusion reactions. It will be important that institutional support will continue in order for Dr. Morita's group to keep its activities and contributions to the field.

Research objectives:

There should be no objection that the physics of superheavy elements is one of the most important research areas in low-energy nuclear physics. The identification of new elements will illuminate our understanding of the nuclear many-body problems.

Research results:

An observation of the third event for the synthesis of the Z = 113 element will be scientifically significant and will provide a large social impact.

Management of the Laboratory:

I should mention that, although Dr. Morita himself is a good physicist, the research achievements of the Laboratory could not have been obtained without the contributions of the staff members, especially the permanent staffs. In the interviews with the staff members of the group, many of them expressed that they are satisfied with the research atmosphere of the group. At the same time, they also mentioned that they often feel a lack of manpower. After Dr. Haba has moved to another group in RIKEN, it would be desirable if the addition of personnel, possibly in the field of nuclear chemistry, could happen.

Future research plans: possibility of cooperation with related fields, etc.

So far, Dr. Morita’s group has focused mostly on the synthesis of new elements. This strategy is acceptable during the first 5 years since the Laboratory was established in 2006. However, I would like to encourage them to extend their view to somewhat more physics aspects of superheavy elements, such as reaction dynamics of heavy-ion fusion reactions, including system and energy dependence of fusion cross sections, spectroscopies, and dynamics of alpha decays and fission. For example, a measurement of energy distribution of a projectile-like particle at backward angles for the reactions relevant to SHE will provide valuable information on how nuclei collide, how nucleons are transferred from one nucleus to the other, and how the incident energy is dissipated into internal energies. The many-body aspects of alpha decays and fission are also important topics, which have not yet been fully understood.

Overall assessment:

The achievement of Dr. Morita’s group in the past 5 years is highly evaluated. Their research should be highly encouraged.

Other opinions:

I found it a good system that there is no chair person among the reviewers, particularly because the number of the reviewers is small. On the other hand, it would have been better if there was a more detailed instruction on how we should proceed the interview with the staff members. In fact, it would have been better if we had a chair person at least in the interview sessions. At first we were a little bit confused on how we should start, how to proceed and what to ask, although we gradually got used to the process.

【Reviewer D】

Research objectives:

Novelty Synthesis of The New Element Z=113 has been attempted so far only at Dubna, in Russia. In this sense, the group's attempt is quite new at this moment, and their attempt should be highly evaluated as long as they can succeed in the synthesis by their method.

It should also be pointed out that only two attempts of finding new elements have been recorded in the history of science of Japan. The first one was reported by Professor M. Ogawa of Tohoku University who claimed the discovery of a new element of Z=43 by chemical analysis of an ore, thorianite and named it "Nipponium" while he stayed with Prof. Sir W. Ramsay in England in 1904. It turned out recently to be not Z=43 but Z=77 rhenium which was truly a missing element at that time. The second one was an attempt to discover Z=93 Neptunium by the group of Dr. Nishina with Prof. K. Kimura at RIKEN around 1940. They discovered a new nuclide of U-237 which decay by beta to the suspected new element Z=93. But they could not separate out and identify the nuclide 93-237 the isotope of the new element by chemical technique of milking procedure.

Scientific significance: Reports on the production of New SHE have been approved by the Joint Working Party(abbreviated hereafter as JWP) of IUPAP and IUPAC only for even Zs up-to Z=116 ,namely, 112,114 and 116. Synthesis of odd Z elements is more difficult compared with the even ones. Besides, understanding of their nuclear stability and detailed nuclear structures is essential for the study of much heavier super heavy elements.

Research results, originality, scientific significance;

Research topics are very versatile, and they are centered around

1) The synthesis of a new element Z=113 and 2)nuclear spectroscopy of various isotopes such as Bh-266,Db-262, Hs-263,Hs-264 and Rf and Sg istopes and 3)studies on the chemical properties of heavy elements including a heavy actinide No(Z-102). The measurement of the redox potential of nobelium for the first time in the world should be also highly appreciated. Also, their results on the ion-exchange property of Sg are based on good statistics of the number of events(atoms), and published in the ordinary chemical journal for the first time (up to then, chemistry papers on SHE were mostly published in more specific journals, for example, Radiochimica Acta) in such a journal as Journal of American Chemical Society.

2) Their efforts to develop new experimental facilities and equipments should also be appreciated. For example (1) GARIS II, (2)data acquisition system by using flash ADC(by Morimoto) and Gas- jet transport system coupled with GARIS(by Kaji and Haba). These developments of facilities are essential for achieving the very low background experimental conditions for observing rare reaction products, with high transfer efficiency and for carrying out fast observations of decays of SHE nuclides (nuclear spectroscopy).

Management of the Laboratory

It was a big surprise for me to find that each laboratory member was all satisfied with the present research conditions even though I suspected from the number of works they achieved and published that they might be over-working to produce so many versatile and high-quality experimental results with the small number of researchers present in the group. They must be all capable hard workers. None of them has any complaint about their leader nor working environments.

Although JAERI at Tokai initiated the SHE chemistry in Japan and it will organize a workshop on SHE Chemistry in Japan this year. RIKEN is now “The center of Super Heavy Element Science” not only in Japan but also in the world. The next TAN (Trans Actinium Nucleus) symposium is scheduled to be held in Japan. It was held at Sochi in Russia this year where it was decided that next one should be held in Japan.

Future research plans: the possibility of cooperating with related fields, etc.

They have very effective collaboration with universities, nuclear chemistry groups at Osaka University and Niigata University. So, the activity of the group is effectively supported by young graduate students, and in turn, RIKEN is offering the precious occasion for the education of young people of the next generation.

The number of formal RIKEN researchers in the group is limited, some considerations from the personnel standpoint may need to be given to the SHE group to take the advantage of RIKEN, good accelerators and the ability of scientists carrying out new Science of Super Heavy Element.

Overall assessment

The group is doing excellently well from the viewpoints of scientific productibility and human relations within the group. However, it is recommended to reconsider the present main project of the synthesis of Z=113. Also, some considerations should be given to the composition of the group, namely, the number of researchers of the group.