EPS-AG 2011 GERSH BUDKER PRIZE PRESENTAION: RETROSPECTIVE OF MY 24-YEAR "RIBF LIFE"

Yasushige Yano
RIKEN Nishina Center, Wako-shi, Saitama, 351-0198, Japan

Abstract

Ever since joining RIKEN in 1979, I have devoted my effort into the construction of heavy ion accelerator facility and the promotion of nuclear physics and applications of heave ion beams. In December 1986, I completed Japan's first ring cyclotron (separate sector cyclotron) named RIKEN Ring Cyclotron (RRC) under Professor H. Kamitsubo, and in 1987, immediately next year I proposed "RI Beam Factory (RIBF)" as my dream, which eventually led to the creation of the world-class RI beam facility. Then, in 1997, eight years later, the RIBF project was approved, and I undertook the construction of the RIBF with the world's first superconducting ring cyclotron (SRC) as its main component. In December 2006, 20 years after the commissioning of the RRC cyclotron, I successfully led the new facility to begin its operation. Currently the RIBF is being utilized by the international nuclear physics community as the world's leading fast RI beam facility. In April 2006, the RIBF, the RIKEN BNL Research Center in USA, and the RIKEN RAL Muon Facility in UK were integrated to create the RIKEN Nishina Center for Accelerator-Based Science; and I was appointed as the first director of the Center. In September 2009, three and half years later I step dawn; and now, I am devoted to upgrading the RIBF as the senior advisor to the Center. In the presentation, I look back on my 24 struggling years (from 1987 up to 2011) devoted to the RIBF project.

PRESENTAION

I would like the readers of this manuscript to refer to my transparencies which I displayed in the prize presentation session (they are included in the present proceedings.)

The followings are the presentations for each slide. Some more information is added.

Slide No.1

First of all, I would like to express my sincere gratitude to the selection committee of IPAC'11 for selecting me as the winner of the prestigious Gersh Budker prize for 2011 with such fantastic and encouraging words.

I indicate the key words in red fonts: the world's first superconducting sector-magnet cyclotron. And the last phrase is most resonating to me: unparalleled capabilities for years to come.

I feel highly honoured to receive this prize.

And also I am very pleased to receive the prize at the same time as Professor S. Kurokawa.

Slide No.2

Let me begin with brief introduction of the RIBF as the prologue of my talk.

This aerial photograph shows the RIKEN's Wako-city campus near Tokyo, whose location is very convenient to access downtowns in Tokyo.

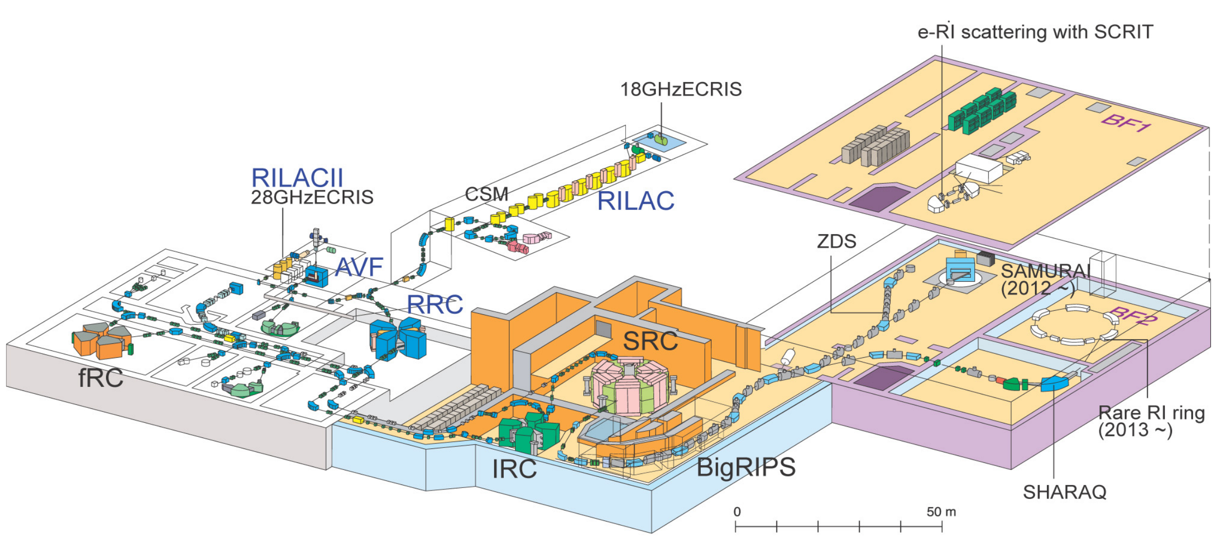
The RIBF is situated in the red zone.

When we look at this zone closely,

Slide No.3

This is the close-up view of the RIBF site.

The RIBF consists of the 22-year old facility and the



new facility. These two facilities are connected to each other underground.

The basement building houses the two old cyclotrons (AVF and RRC), the three new cyclotrons (fRC, IRC and SRC) and the new RI beam separator (BigRIPS). The number indicated starts with the Dr. Nishina's No.1 and No.2 cyclotrons shown later. The RILAC heavy-ion linac is housed in the ground level building.

Slide No.4

This is the layout of the RIBF [1]. (See also the figure in the bottom of the previous page.)

The RIBF is now capable of providing all ions at 345 MeV per nucleon [2]. RI beams are produced via in-flight uranium fission or projectile fragmentation of stable isotopes.

Take uranium-fission for instance, a uranium 35+ beam obtained from the 28 GHz superconducting ECRIS [3] is pre-accelerated by the newly operational RILAC II [4], and injected into the old RRC cyclotron. The energy of the RRC beam is boosted up to 345 MeV per nucleon by the new cyclotron cascade of fRC, IRC, and finally the superconducting ring cyclotron, SRC [5]. The 35+ uranium ions are charge-stripped twice before and after the fRC cyclotron, from 35+ to 71+ at 11 MeV per nucleon and also from 71+ to 86+ at 51 MeV per nucleon. This charge stripping is now processed by the ordinary thin carbon foil (presently, the short life-time of the stripper is the serious bottle neck to increase the uranium beam intensity.) The 345 MeV per nucleon uranium beam from the SRC is transferred to the production target, and fission fragments are isotopically selected and collected by the large-acceptance superconducting BigRIPS [6].

Currently, superconducting Zero Degree Spectrometer (ZDS) [6] and SHARAQ spectrometer [7] are used for the experiments, and the large-acceptance superconducting SAMURAI spectrometer [8] will be commissioned for experiments early in 2012. The unique electron-RI scattering ring with Self-Confining RI ion Target, SCRIT has been completed [9]. This ring will allow the precision measurement of charge distribution, namely proton distribution inside unstable nuclei for the first time. The Rare-RI ring will be completed in 2013 [10]. It will allow the precision mass measurements with the accuracy better than 1 p.p.m. for quite rare RI's with 1 particle per day productivity.

Slide No.5

The RIBF is now exhibiting its powerful potentiality to explore the nuclear world which has never been accessible.

In November 2008, 45 new radioactive isotopes were discovered in only 4-day experimental run and with only 0.3 pnA beam intensity [11].

Among them, palladium-128 is speculated to be the origin of the second peak in the solar isotope abundance.

In another two years, this uranium beam intensity will be increased by 400 times by installing a novel pressurized He-gas charge stripper whose life-time is infinite. This decisive breakthrough has been invented by my younger colleague, Dr. H. Okuno [12].

Slide No.6

The RIBF will greatly expand our known nuclear world up to around pink-coloured (in-flight fission) and sky blue-coloured (projectile fragmentation) regions, which contains hypothetical r-process pathway (green arrow) to create the uranium element at the moment of super nova explosion, when we will achieve 1 pμA primary beam intensity for all ions. The RI-intensity produced at the edge of the regions is estimated by the GSI's simulation program EPAX2 [13].

Big challenge to solve the big mystery of the element genesis has begun.

Slide No.7

Now, so much time has spent for the prologue.

This is my title of the today's talk. Let me look back on my struggling 24 years devoted to the RIBF project, from 1987 up to this year.

The RIKEN Nishina center [14] established in 2006 is also my creation, which is the first Japanese research center named after one of our great pioneering scientists. Dr. Nishina is called the Japanese father of nuclear science, and he fostered Japanese first two Nobel Prize winners, Professors H. Yukawa and S. Tomonaga. And also the development of Japanese accelerators has been initiated from his cyclotrons. I spent three and half years as the first director of the RIKEN Nishina Center, and now my younger colleague, Dr. H. En'yo has succeeded me and Professor W. Henning, the former director of the GSI, has been appointed as the deputy director in charge of the RIBF.

Slide No.8

This is my memorial photo of us celebrating the first beam extracted from the RRC cyclotron. Memorable moment came at 15:34 on December 16, 1986.

20 years later the first beam came out from the SRC cyclotron.

Slide No.9

In 1987, the next year, Prof. M. Ishihara and I wrote the news article on the commissioning of the RIKEN Ring Cyclotron in the Japanese popular science magazine "Parity". The photo of the RRC cyclotron is exhibited on the cover page.

In this article, we wrote that our future dream is to create the world's leading "RI beam factory".

Slide No.10

And also in the same year, when the discovery of high Tc superconductivity was in fever, I was invited to attend a panel discussion on superconductivity and atomic energy and in this panel presentation I showed up a very conceptual drawing of the RI beam factory based on superconducting sector-magnet cyclotron. In my scheme I would add an SRC and an RI beam collider downstream of the then newly operational RRC cyclotron.

Slide No.11

In 1995, eight years after the RRC commissioning, a two-year R&D budget of nearly $2M, was approved.

By then, the RIBF planed consisted of the single big 150 MeV per nucleon SRC and a MUlti-use Experimental Storage rings, MUSES [15]. The MUSES aimed at realizing the world' first electron-RI beam collider.

But this SRC included a serious problem in its design.

Slide No.12

In 1996, the next year we had to conclude that the beam injection to this SRC was impossible, because the central region was too narrow to set up the injection elements.

My God: this was the first hurdle we struggled to overcome.

Slide No.13

Incidentally, the same year I was phone called by Professor B. Sinha, the then director of the VECC, in Calcutta, India to come to his office to take this photo for us shaking hands to celebrate the conclusion of the MOU. During the flight from Narita to Calcutta, I came up with an idea that the single big SRC should be split into smaller, but with larger central region SRC and an IRC cyclotron whose structure is similar to the RRC.

The insertion is my memo in the travel note book where I jot down this idea. The word "IRC" is seen.

Slide No.14

In 1997, the construction budget was approved. In the figure "SRC" and also "IRC" are seen [16]. We requested $750M in total, but I was strongly requested by the government to reduce this cost by significant amount.

But, then we still had serious problems for the SRC design.

Slide No.15

In 1998, next year, I concluded that this SRC design included too many technical problems to be solved to realize it and all the problems are due to large valley-region leakage-flux in the long run.

My God! After recognizing this desperate design drawback, I could not sleep well, until, in 1999, I decided to cover whole the valley-regions with thick iron plates to absorb leakage flux. This was the simplest solution to solve all the problems [17].

The only thing was: required volume of iron amounts up to 8,000 tons, 1,000 tons heavier than the Eifful tour in Paris.

Slide No.16

And in this way, the world's first, strongest and heaviest SRC was born. This structure has self-radiation shielding capability as well.

Slide No.17

In November 2005, full excitation of the SC sector magnets was achieved.

Slide No.18

This diagram shows the yearly trends of iron price from 1980 to 2006. We purchased 8,000 tons at the bottom.

In order to create super-facility, the "luck" is indispensable.

Slide No.19

So, next hurdle: in 1999, an RIA project of USA based on the SC linacs was proposed, and the "white paper" of the project stated that the 150 MeV per nucleon uranium beam which the RIBF project plans is insufficient to efficiently produce RI beams by in-flight fission. Instead, 400 MeV per nucleon should be achivable [18].

My God!

Then, in 2001, I decided that we add one more inexpensive cyclotron, fRC to upgrade the final energy up to 340 MeV per nucleon. Moreover, BigRIPS should be a large-aperture SC separator which can accept large-emittance fission fragments.

These are the present design [17].

Slide No.20

The first beam was extracted from the SRC at the moment indicated in this slide.

I had been declaring for years to the international accelerator community that the first beam would be coming at the following moment: sharply 20 years after the first beam from the RRC cyclotron.

A little bit delayed! But we almost well did it [19].

Slide No.21

"Science" magazine and "Nature" magazine reported the completion of the RIBF.

Slide No.22

In June 2007, the International Nuclear Physics Conference (INPC'07) was held in Tokyo, and I was given an extra session to deliver the flash report on the first outcome from the RIBF: the discovery of a very neutron-rich new isotope palladium 125, by the in-flight fission of 345 MeV per nucleon uranium beam. Incidentally palladium 112 was the discovery by Dr. Nishina's cyclotron [20]. In his experiment, he discovered much more surprising "symmetric fission" of uranium by fast neutrons unlike then well-known "asymmetric fission" by slow neutrons.

In closing my talk, I declared that the great endeavour has begun to explore the nuclear world which has been inaccessible so far.

In the opening session of the conference, the Emperor delivered a very moving message to the audience about the tragedy of Japan and Japanese people caused by the atomic bombs and the role of nuclear physics community.

Slide No.23

Incidentally, during my directorship since 1992, I enjoyed the honour of guiding the Emperor on a tour of our cyclotron facilities twice, first in 1992 and then in 2006. Younger myself (left-hand-side photo) and also myself fourteen years later (right-hand-side photo) are seen in these memorable photos. I believe that now Japanese Emperor and Empress are the most informed royal couple in the world about cyclotrons.

Slide No.24

How about the MUSES?

In 2001, the GSI reported that the luminosity obtained in the MUSES is too low to create scientific impacts, because the RIKEN system is based on DC beam, not on pulsed beam.

We absolutely agreed!

So, in 2003, I decided to give up the MUSES project, while, instead, I decided to construct much better cost-effective high-performance alternatives: namely, the SCRIT, for precision charge-distribution measurement by electron scattering (this novel scheme is my younger colleague, Dr. M. Wakasugi's invention) ,and the Rare RI ring for precision mass measurement.

Slide No.25

The top is the picture of the electron-RI scattering system completed, and the bottom is the principle whose essence is that we utilize the unfavourable "ion trapping" phenomena positively. We published two PRL papers on the experimental proof of principle [21].

Slide No.26

So, here we are at last: Epilogue.

One day before the IPAC'10 last year, "Special lectures to commemorate the 120-th anniversary of Birth of Yoshio Nishina" was held.

In this lecture meeting, these distinguished Professors presented the talks about Dr. Nishina and advancement of particle accelerators and their applications in Japan.

One of the lecturers, Professor M. Craddock, spoke about a very suggestive and impressive review story of Japanese cyclotrons from Dr. Nishina's pioneering work up to present RI-Beam Factory. The lecture notes are viewed on the RIKEN Nishina Center's home page.

Slide No.27

In this slide, I would like to show you Dr. Nishina's cyclotrons. This old aerial picture shows the original RIKEN campus which was located near the center of Tokyo.

On the top-right corner of this picture, there used to be Nishina's laboratory. The two buildings indicated in white dots housed his No. 1 and No.2 cyclotrons.

The No.2 cyclotron, commissioned in 1944 just before the end of World War Two, was the world's largest cyclotron at that time, and was about to start experiments.

Slide No.28

But, as many of you know, these cyclotrons and at the same time Dr. Nishina's dream was killed by the War as shown in this "Life" magazine issued in December 1945.

What a shame!

Slide No.29

Since then, sixty six years have passed.

I believe now, Dr. Nishina's dream has been realized.

But, my dream will take a little more time to come true.

Slide No.30

Finally, I wish to give my special acknowledgements to: many, many Japanese and foreign colleagues and collaborators, and the presidents of RIKEN, especially, Professor A. Arima. Without his strong support, this big project could not have started.

And, I wish to give my many thanks to the International Advisory Committees (IAC's) and the International Technical Advisory Committees (TAC's) of the RIBF project who continuously have led us to the right way, to the Governments who have strongly supported this project, and also the companies who have helped us to eventually realize the RIBF.

Thank you for your kind and patient attention to my very personal story!

REFERENCES

[1] Y. Yano, "RIKEN RI Beam Factory Project: Status Report", Nucl. Instrum. Meth., B261 (2007), 1009.

[2] O. Kamigaito et al., "Status of RIBF Accelerators at RIKEN", Proc. of Cyclotrons'10, (to be published).

[3] Y. Higurashi et al., "Developments of RIKEN New Superconducting ECR Ion Source", Proc. of IPAC'10, p. 4191.

[4] K. Yamada et al., "Construction of New Injector Linac for RI Beam Factory at RIKEN Nishina Center", Proc. of IPAC'10, p. 789.

[5] H. Okuno et al., "Commissioning of the Superconducting Ring Cyclotron for the RIKEN RI Beam Factory", IEEE Trans. Appl. Supercond., 18 (2008) 226.

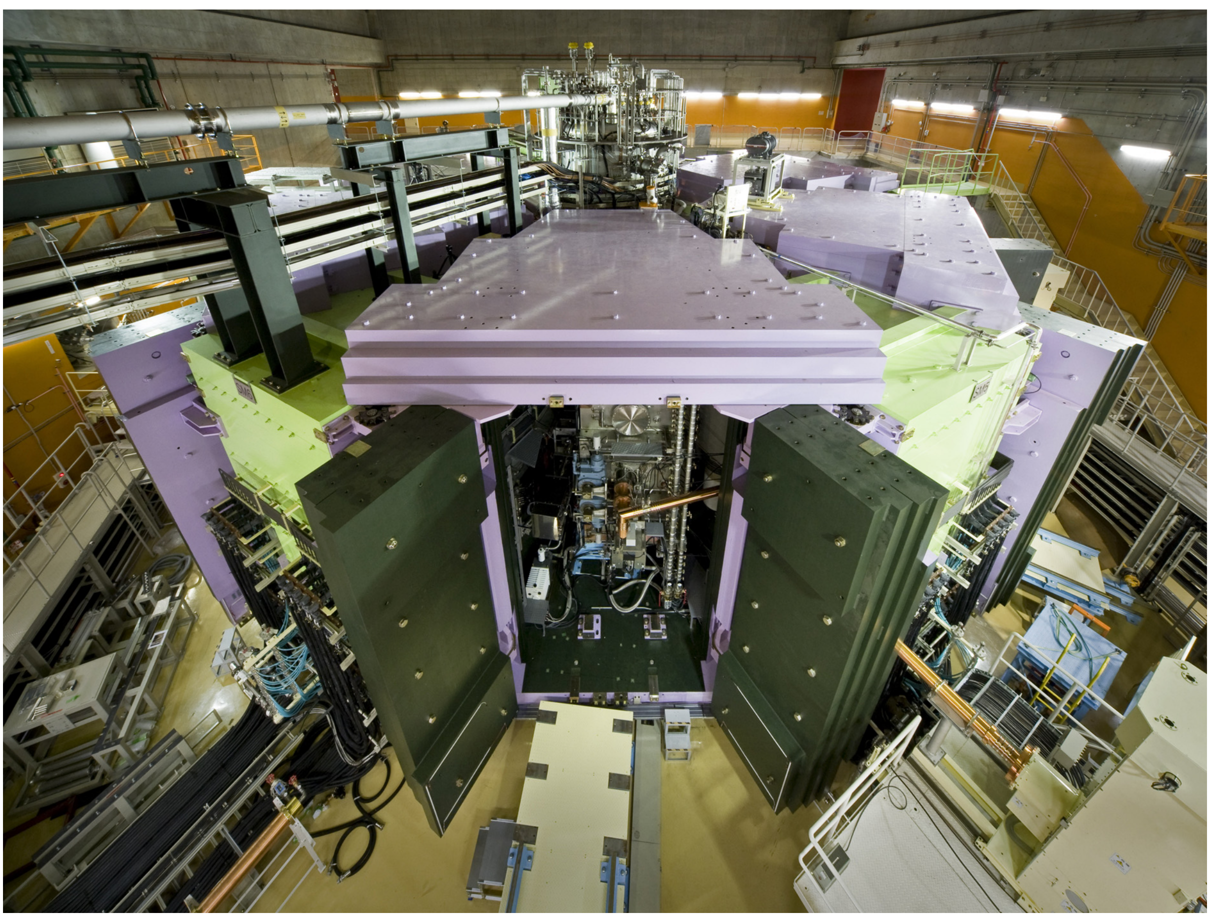
[6] T. Kubo et al., "Status and Overview of Superconducting Radioactive Isotope Beam Separator BigRIPS at RIKEN", IEEE Trans. Appl., Supercond., (2007) 171069.

[7] S. Uesaka et al., "SHARAQ Spectrometer - Current status and future experimental plans", AIP Conf. Proc. 1224 (2010) 573.

[8] Y. Shimizu et al., "SAMURAI Project at RIBF", The International Nuclear Physics Conference 2010, INPC2010, July 5, 2010, University of British Columbia, Vancouver, Canada, J. Phys, Conference Series, to be published in 2011.

[9] M. Wakasugi, T. Suda, and Y. Yano, "A New Method for Electron-Scattering Experiments Using a Self-Confining Radioactive Ion Target in an Electron

Storage Ring", Nucl. Instrum. Meth., A532 (2004), 216.
[10] Y. Yamaguchi et al., "Rare-RI ring project at RIKEN RI beam factory", Nucl. Instrum. Meth., B266 (2008), 4575.
[11] T. Ohnishi et al., "Identification of 45 New Neutron-Rich Isotopes Produced by In-Flight Fission of a ^{238}U Beam at 345 MeV/nucleon", Journal of Phys. Soc. of Japan, 79 (2010) 073201.
[12] H. Okuno et al., "Low-Z gas stripper as an alternative to carbon foils for the acceleration of high-power uranium beams", Phys. Rev. ST Accel. Beams 14, (2011) 033503.
[13] K. Suemmerer and B. Blank, Phys. Rev. C61 (2000) 034607.
[14] Visit to "http://www.nishina.riken.jp/".
[15] Y. Yano and T. Katayama, "Present Status and Future Plan of RIKEN Accelerator Research Facility", Proc. of EPAC'94, p. 515.
[16] Y. Yano, A. Goto and T. Katayama, "RIKEN RI Beam Factory Project", Proc. of PAC'97, p. 930.
[17] Y. Yano, A. Goto, M. Kase and T. Katayama, "RI Beam Factory Project at RIKEN", Proc. of CYCLOTRON'01, p. 161.
[18] ISOL Task Force Report to NSAC, 22 November 1999.
[19] Y. Yano, "Status of the RIKEN RIB Factory", Proc. of PAC'07 (2007), p. 700.
[20] Y. Nishina, T. Yazaki, K. Kimura and M. Ikawa, "Fission Products of Uranium by Fast Neutrons", Nature (1939) p. 660.
[21] M. Wakasugi et al., "Novel Internal Target for Electron Scattering off Unstable Nuclei", Phys. Rev. Lett., 100, (2008) 164801; T. Suda et al., "First Demonstration of Electron Scattering Using a Novel Target Developed for Short-Lived Nuclei", Phys. Rev. Lett., 102, (2009) 102501.



Photograph of the SRC when the side yoke shields are open. You can see the RF cavity inside.