RIKEN Nishina Center
Advisory Committee Report

Submitted on September 7th, 2023

NCAC Meeting July 24-26, 2023

Report: Findings/Comments and Recommendations from *the NISHINA Center Advisory Council (NCAC)*

I. Executive Summary

Introduction

The NCAC wishes to thank RIKEN President Makoto Gonokami, Executive Directors Kohei Miyazono and Minoru Yoshida, Nishina Center Director Hiroyoshi Sakurai, as well as all the members of the RIKEN Nishina Center (RNC) for their hospitality. The NCAC appreciates the considerable efforts made in presenting the details of the past and planned activities of the RNC carried out by the research divisions, both locally and overseas, as well as the mid-term management and scientific strategy for future projects. The NCAC was impressed by the excellent preparation for this meeting. The NCAC commends the RNC team for the high quality of the preparatory documents and the clarity of the presentations during the review. This as well as the transparent and direct exchanges with RNC management and presenters during this three-day meeting were instrumental in facilitating this NCAC review. The NCAC would also like to take the opportunity to thank previous RNC Director Hideto Enyo for his leadership of the RNC for over a decade.

In this Executive Summary, the NCAC will address the three main charge elements at a high level. The remainder of the report will provide a more detailed assessment of the performance of the RNC in the 4th Mid- to Long-Term Plan period in various areas of the organization, as well as the Scientific Strategy and Management Policy Plan for the 5th Mid- to Long-Term Plan period. This part of the report is organized in Findings, Comments, and Recommendations.

Responses to the 2019 NCAC Recommendations

The committee appreciates the detailed response by the RNC team to the recommendations from the 2019 NCAC meeting. The NCAC is overall satisfied with these responses and has the following specific comments here with further follow-up on some of these topics included in the remainder of the report:

- RNC management has clarified which performance indicators are being tracked and NCAC sees opportunities to strengthen the use of performance indicators by making them visible for all and across all program parts, and include publication impact.
- The NCAC appreciates that RNC management acknowledges that increase of gender diversity is a major issue for RNC and RIKEN and that a working group has been formed. However, the NCAC did not see any changes in diversity at RNC or the development of an effective strategy to increase gender diversity among the PIs as well as research and technical staff. This topic has again been a significant concern during this NCAC meeting and will be discussed further later in this report.
- The NCAC is pleased to see that the medical isotope production capabilities have been significantly expanded and numerous isotopes are being made available for medical research across Japan. The aspect of intellectual property rights needs to be considered.

- The NCAC is pleased to see that additional links with universities have been established and numerous MoUs with international research partners are in place.
- The transmutation related activities were impeded by the lack of resources after the end of the ImPACT project and the conceptual design of the 1A-class linac is still underway. The RNC should establish a plan and set priorities related to transmutation related activities.
- Links of astrophysics projects with other experimental and theory groups at RIKEN and outside RIKEN are shown to be part of the overall program. Their coordination and synergies may benefit from an overarching annual coordination effort.
- The NCAC sees the new hire of a PI for low energy nuclear theory as an important step towards strengthening the theory effort at RNC.
- The NCAC appreciates that the sub-nuclear physics efforts, which have been integrated into the Nuclear Science Research Division, are undergoing significant changes since the last NCAC meeting and the previous NCAC recommendations have to be reevaluated in that context, which will happen later in this report.
- The NCAC is pleased to see that the Instrument Development and Accelerator Group were able to strengthen the connection to the universities with new affiliations and providing lectures. However, the pandemic did not allow an increase of students in Accelerator Science at RNC. NCAC encourages the Accelerator Group to engage more students in the unique RNC accelerator and instrumentation development projects.
- The NCAC is happy to see that the RIBF upgrade project has been developed and a funding proposal submitted. NCAC will comment on this proposal later in this report.
- The NCAC took note of the renewal of the MoU for RBRC and the successful completion of the RIKEN-RAL center with transition of expertise to RAL and a continued MoU for high-level partnership between RNC and RAL.

Performance in the 4th Mid- to Long-Term Plan period (FY2018-2024)

Governance and management to maximize R&D achievements

The NCAC commends the RNC leadership for managing the operations of the RNC in an effective way in particular in view of challenging budgets as well as global events.

Most recently, the RNC management has continued to optimize the organization of the RNC by aligning it to the three RNC strategic pillars of Science, Innovation and Technology. The NCAC sees this as an opportunity for enhanced interactions between laboratories and groups in particular within the Nuclear Science Research Division.

Creation of world's highest level of research results

The RIKEN Nishina Center has continued to create excellent research results across its whole portfolio addressing overarching questions of "How were elements created by the universe?" and "Can humans change the elements at will?". Noted highlights from RIBF include isotope

discoveries on the neutron-rich and neutron-deficient side of the nuclear chart, the study of the magicity of key neutron-rich nuclei ^{78}Ni and ^{28}O and exploration of the neutron magicity from N=34 to N=40, the discovery of a correlated tetra-neutron system, as well as pioneering studies of neutron-rich nuclei for r-process nucleosynthesis. The successful coupling of MR-TOF spectroscopy to the gas-filled separator GARIS-II resulted in the first high-precision direct determination of the atomic mass of a superheavy nucleus (^{257}Db). The experimental efforts in low-energy nuclear physics are complemented by highlights in nuclear theory, including unraveling multi-neutron correlations, predictions of new hypernuclei, and fusion reactions of astrophysical interest. In addition, major breakthroughs were achieved in the context of the RBRC on the gluon polarization, addressing the proton spin puzzle.

Furthermore, the detectors for space missions in X-ray astronomy have led to new discoveries, and Astro-Glaciology has provided interesting insights into solar activity and climate impacts while maturing their pioneering ice core melting and analysis device.

Finally, the NCAC would like to congratulate the RNC for the successful conclusion of the science 30-year program of the RIKEN-RAL center, leading to over 500 publications.

Research initiatives for operation, sharing, upgrading, and utilization of R&D infrastructure

The NCAC commends the RNC for achieving excellence in the operation of the RNC accelerator complex during the period FY 2018-2022 with high percentage of beam delivery achieved during this period. At the same time the NCAC is concerned about the extended down time incurred in 2023 due to lack of spares and an adequate beam protection system. In addition, several important improvement and technical upgrade activities were successfully carried out with support from supplementary funding. These will help to ensure continued reliable operation of the accelerator systems.

The completion of the SRILAC linear accelerator for the superheavy element research is another highlight for establishing world-class R&D infrastructure and the >99% operational reliability of the superconducting accelerator components is truly impressive. The NCAC also applauds the RNC for the new developments for SAMURAI which include detection, target, and electronics upgrades which will expand the scientific reach of this key spectrometer even more. Additional highlights are the progress made on the Self Confining RI on Target system (SCRIT), invented at RIKEN, and the development of X-ray detectors for international space missions in astrophysics.

Another noteworthy technical achievement was the completion and subsequent improvement of the world’s first laser melting sampling device for the investigation of ice core samples, enabling exciting research on astro-glaciology. The realization of the sPHENIX tracking detector INTT will enable RHIC to complete its scientific mission of the study of the quark gluon plasma.

Through its pioneering research in experiment, theory, and advanced computing, the RNC is excellently positioned to connect to the TRIP concept, and the NCAC commends the RNC for identifying a first society-benefit TRIP case on nuclear transmutation.

Applications and societal impact

The RNC has made important and highly recognized contributions in the advancement and utilization of research results and the creation of new knowledge with important societal impact. A noteworthy example is the transmutation research carried out through the ImPACT project, which not only advanced important technical aspects for realizing nuclear waste transmutation but also generated four patents.

The Astro-Glaciology Laboratory not only investigates the supernova rate in the vicinity of the solar system across the recent million years but also makes significant contributions to our understanding of the climate record of the planet.

Additional highlights are the activities in medical radioisotope production which can be regarded as extremely important for RIKEN as an enabler of basic and applied research in fields other than nuclear physics and chemistry, notably cancer research.

Furthermore, the strong research and collaborative efforts of the Ion Beam Breeding Group have positioned it as a recognized global hub in the field for fundamental understanding as well as applications for societal benefit. 39 crop varieties developed with ion beam radiation are currently in the market.

The RNC irradiation facility for tests of electronics that are dedicated to application in space exploration is used extensively by industry with growing demand and a broadening of the user base. The NCAC commends the RNC for supporting these important applications.

The RNC has also been very active in engaging with the public through press releases, popularizing its research results, as well as public tours and participation in other outreach events. Another example is the popular Japanese book “Deep learning and physics” co-authored by RBRC theorist Akio Tomiya.

Nurturing and recruiting of research talent: Brains Without Borders, Diversity

While RIBF continues to attract a large number of international users from around the world every year, the number of non-Japanese researchers working at the RNC has remained roughly constant over the past years. Similarly, the number of female researchers and PIs has not improved in this review period. Stronger efforts need to be made by the RNC and RIKEN leadership to attract female researchers.

Policies for the 5th Mid- to Long-Term Plan period (FY2025-2031)

The NCAC acknowledges that the RNC provides unique value to RIKEN in particular in support of the goals set out in RIKEN's Vision on the 2030 Horizon. The NCAC also considers the ongoing TRIP use case on nuclear transmutation as a success. The NCAC sees substantial opportunities for additional use cases that can further the existing science goals of the RNC program, for example around ion-beam breeding or medical isotope applications, advanced computing, or support goals for sustainability and energy efficiency improvements for the accelerator facility.

The NCAC strongly endorses the plans for the optimal operation of the RNC accelerator facility in the next period. The NCAC emphasizes that it is important to fully utilize the RIBF facility by enabling sufficient annual running time for the world leading RI beam program in nuclear structure and dynamics. Sufficient operational funding and staffing for efficient and reliable operation is critical for the success of the RNC program. Training the next generation of scientists and engineers as well as increasing diversity also need to be priorities. The RNC should take full advantage of existing partnerships between RIKEN and its partner universities.

The NCAC also strongly endorses the efforts in search of new superheavy elements. Major questions in astrophysics are addressed by RNC research on several fronts and the NCAC sees potential for strengthening the connections between the programs and between the RNC and other RIKEN efforts. To maximize the science return and for future planning at RIBF, strong leadership in nuclear theory at RIBF is critical and the NCAC would like to see the theory efforts be further strengthened.

The RNC will continue to drive important applications of nuclear science, such as the world-leading ion beam breeding efforts, space effects irradiations and medical isotope production, which will have tremendous impact for society.

International collaboration continues to be an important element of the RNC's strategy. This includes attracting researchers and key equipment from around the world to the RNC. At the same time, the continuation of the very successful collaborations with BNL needs to be emphasized. The NCAC strongly endorses the engagement with sPHENIX, which is starting operations concurrently, and is looking forward to the development of an EIC-Japan collaboration on the ePIC detector for the Electron Ion Collider (EIC) at BNL.

In light of the international landscape with major rare isotope accelerator facilities like FRIB and SPIRAL 2 ramping up and FAIR and ARIEL in the future, it is critical for the sustained success of RIBF to stay at the forefront of the field. The science program enabled by the RIBF upgrade is exciting, in particular by opening access to isotopes at the extremes of the nuclear chart, which are important for understanding the origin of the heavy elements and the limits of existence of atomic nuclei. **The NCAC endorses the proposed RIBF upgrade in the strongest possible terms.**

II. Organization, Management, Personnel and Budget

Findings:

- As of April 1, 2023 the RNC underwent a reorganization, aligning the organizational structure with the 3 strategic pillars of Science, Technology, and Innovation. Efforts in experimental and theoretical research from low- to high-energy nuclear physics were combined into the Nuclear Science Research Division. Applied activities, including Transmutation, Ion Beam Breeding and Nuclear Chemistry research are now combined in the Accelerator Applications Research Division.
- Total staff has dropped from 148 in 2018 to 133 in 2022 with a drop in permanent researchers (76 to 70), postdocs (12 to 9) and junior research associates (16 to 7). At the same time, the NCAC was informed that the RNC is carrying out strategic recruitment of young postdoctoral fellows in the infrastructure groups (accelerator, instrumentation and safety groups) as part of succession planning.
- The evolution of the number of female and non-Japanese staff members and PIs was presented and there has been no significant change over the last 5 years. In fact, the number of female researchers on staff went down from 13 to 11 in 2022.
- In 2021 a working group on diversity and inclusion was formed, which has launched a project to highlight the diversity in gender and nationality among the research staff on a web-site that was developed by high-school and undergraduate students. The working group is also now working on a diversity statement that is to be completed in 2023.
- The Accelerator Science Research budget continues to decline from FY 2018 to 2022 but this decline was in part compensated by supplementary funding as well as the newly established RIKEN Depository funds
- The RNC Director presented the safety record of RNC. In spite of a rise in the number of incidents observed in 2022 compared to previous years, this number stays at a very low level.
- RNC IP management is organized in collaboration with “RIKEN Teigyo”. Four patents originating from R&D in the ImPACT project were registered. The target R&D for At-211 production takes place in collaboration with a company and all newly developed breeds are registered.
- Part of the User Liaison Office responsibilities include outreach activities, which include the development of an RNC pamphlet and public facing website, support for public tours of the RNC, participation in Science exhibition events as well as the Nishina school.
- Experiments in the spring of 2020 had to be canceled or postponed due to a COVID-19 related shutdown. Some of these experiments could be carried out later on but due to travel restrictions foreign experimenters could not travel to Japan for some time and experiments that were planning to use equipment owned by the international groups, e.g. MINOS.
- RIBF has typically attracted ~150-200 international users per year, which were not able to travel to Japan during the pandemic. The number of international users has

rebounded after the pandemic, demonstrating the fact that RIBF remains very attractive for the international nuclear physics community.
- The RNC Director presented a SWOT analysis for the center, and articulated a strategy to overcome the weaknesses by maximizing strengths and opportunities through using rare isotope beams to produce results, discovering new superheavy elements, and realizing the RIBF upgrade.
- RNC management is actively encouraging patent applications and IP management is organized in collaboration with “RIKEN Teigyo”.

Comments:

- Safety was not addressed in the Director's talk but all information requested by NCAC was provided after the presentation. This subject should be a topic for the introduction for the next review.
- The NCAC is concerned about the erosion of the accelerator operations budget during the review period. This reduction was compensated in 2022 by funds from the newly introduced depository system, which may, however, not be similarly available in forthcoming years, putting the financial situation of RNC at risk.
- On many technical specialties essential for RIBF operation, the RNC is facing "single point failure" situations where only one specialist is in place, with the risk of having to stop the facility in case this specialist is absent or decides to leave his position (ion source, magnet PS, RF)
- The NCAC is concerned about last year’s personnel reduction, and lack of progress on gender diversity. Since the 2019 review, an effective response to the NCAC recommendation on diversity was not achieved.
- Regarding the efforts in hirings more female researchers, the RNC (and RIKEN) may benefit from implementation of a dedicated search and mentoring program (see example Max Planck Society) to identify a pool, out of which hiring through the Sechi Kato program could occur.
- The reorganization of the RNC that combines discovery research activities across the full spectrum of nuclear physics from low to high energies and combining experiment and theory into a single division provides a good structure for stronger interactions across sub-fields.
- The presented SWOT analysis is a reasonable assessment of strengths, weaknesses, opportunities and threats for the RNC. An additional weakness that should be included is the lack of diversity of the workforce.
- Nuclear Physics is a field which aligns well with the TRIP concept, e.g. through the generation and use of large scale nuclear data, various applications of accelerators for societal use, the need of advanced computing including high performance computing as well as machine learning & AI, as well as the use of technologies valuable for Quantum Computing like superconducting radiofrequency (SRF).

Recommendations:

- The NCAC recommends that RIKEN ensure that the RNC is funded at a level to efficiently operate the full facility to maximize the scientific return of the investment made and ensure RNC remains at the forefront of nuclear physics worldwide.
- RIKEN management is urged to ensure replacing critical personnel for RNC accelerator infrastructure who are currently supported by central RIKEN funds and ensure that these do not create an additional burden for the RNC operational funds.
- The NCAC recommends that the RNC develop a prioritization plan for resource allocation between operational, research, and upgrade activities.
- The NCAC recommends that RNC management set specific hiring goals to increase the fraction of female staff among PIs and other research and technical personnel and hold itself accountable by making one of the Deputy Directors responsible to drive this effort.
- The NCAC recommends that better communication be established between the RNC leadership and researchers from underrepresented groups, e.g. by establishing regular meetings of the Director with these staff members.

III. Research Facility Development Division

Accelerator

Findings:

- RIBF has been operating as the world's highest beam power heavy ion user facility leading the power frontier of heavy ion accelerators.
- The overall facility availability from 2018 to around 2022 is around 90%.
- The newly constructed SRILAC was commissioned in January 2020. Since then, SRILAC has operated for 10 user runs with availability > 99%.
- The desired (“required”) number of the accelerator group staff members is 33 which would require the addition of 11 staff members relative to the current staffing level.
- There has been significant downtime associated with accelerator system failures including vacuum leakage, helium leak, septum electrode damages. Most impactful downtime is attributed to beam induced events.
- Downtime was extended due to lack of spares of the damaged parts.
- There have been efforts enhancing machine protection including monitoring and interlocking upon power supply fluctuations of main magnets. Faster machine protection systems with response time reduced from 15 ms to 0.13 ms is in progress.
- Accelerator improvements have been on-going among major systems of the facility.

Comments:

- The NCAC congratulates the RNC on the continued leading position of RIBF in the heavy ion accelerator community as the world's highest beam power user facility, and noted the excellent progress in accelerator complex operation with the overall availability of 90%.
- It should be noted, in particular, that the SRILAC beam availability reached > 99%, with the SRF technology demonstrating very stable operation.
- Annual beam hours delivered to user experiments, beam tuning, and beam developments were not presented. Neither were projected beam hours presented for future years.
- The accelerator team is to be commended on pioneering cutting-edge technologies including the dual gas charge stripping.
- The RNC has some very talented young scientists ready to lead towards RIKEN's bright future.
- The desired staffing level of the accelerator group at 33 permanent positions is low compared with similar facilities worldwide, even considering that some work is outsourced. The 11 unfilled positions of the accelerator group are of concern.
- It will be important to seek consensus among stakeholders on expected beam time and availability goals given beam-induced machine damaging incidents, failures due to aging equipment and legacy system degradation, and extended downtime associated with RIBF upgrades. A yearly profile of balanced beam time for user experiments, facility tuning, and accelerator complex development will likely facilitate understanding on staffing and other resource needs.
- For a seasoned facility like RIBF, the unscheduled downtime may be divided into three categories, each demanding specific mitigation strategies and dedicated resources allocation: (a) due to beam induced damages requiring improved machine protection system and interlocks; (b) due to equipment failures, in particular attributed to legacy system failures requiring systematic analysis (failure modes, mean time between failures, mean down time) and renovation planning; and (c) due to fundamental technology limitation (e.g. beam dump design to allow for higher beam power, as part of "targetry system" performance limits) requiring longer-term R&D.
- Modern high power accelerators require a multi-layer, multi-time-scale machine protection system (MPS). The response time of the fast MPS is usually ~ tens of microseconds. RIBF's accelerator group's efforts recognize this. Additionally, a machine protection system is preferably complemented by a run permit system managing machine configurations.
- For an aging facility a refurbishment and upgrade program is required. Many activities have been shown but no comprehensive plan with according priorities for the required refurbishment activities has been presented.
- Given post-pandemic supply chain uncertainties, it is particularly important to develop and manage a plan for spares based on systematic analysis of failure modes, mean time between failures, and mean down time.

- Major upgrades of other superconducting accelerator facilities in the world often include cryogenic system renovations in some cases including a modern centralized high-efficiency helium liquefaction system and cryo-distributions. With rapidly rising helium costs in the world market such investment is particularly rewarding. On the other hand, such renovation requires systematic and strategic planning. An extended downtime is also needed for system commissioning. A careful feasibility and cost-benefit analysis is needed.

Recommendations:

- The NCAC recommends that the Research Facility Development Division and the Accelerator Group establish a bottom up staff plan and associated funding needs to ensure the sustained success of accelerator operations and upgrades.
- The NCAC recommends that the RNC develop projections for the profile of annual beam time designated for user experiments, accelerator development and facility tuning considering major shut down for RIBF upgrade and request resources accordingly along with building consensus among stakeholders.
- The NCAC recommends that availability of sufficient spares is ensured based on spares plans developed through a systematic analysis of failure modes, mean time between failures, and mean down time.
- The NCAC recommends that a plan be established of prioritized refurbishments for the next mid- to long- term period, to cope with the aging equipment of the accelerator complex and the increasing beam power to keep the high operational performance.

Research Instrumentation

Findings:

- The BigRIPS team provided 141 secondary beam settings for 85 experiments from FY2018-FY2022.
- The cryogenic system for the Q-triplet is facing difficulty to maintain stable cryocooler operation because of terminated maintenance service by the supplier.

Comments:

- The BigRIPS team is congratulated for their leading role in isotope discovery experiments which have been instrumental to establish the neutron dripline beyond oxygen.
- The “Automatic Operation for RI Beam Production” is an important and impressive effort that holds the promise to significantly reduce beam tuning and PID time, de facto increasing the time for experiments.
- The BigRIPS team is congratulated on the great progress in the PID of high-Z beams through ion optics and hardware/detector upgrades.

- The NCAC applauds the new developments for SAMURAI which include detection, target, and electronics upgrades which will expand the scientific reach of this key spectrometer even more.
- The PPAC detectors that RIBF has been employing in the fragment separator and beam transport system are critical for the facility's secondary beam production and identification and the detector group is commended for their continued development work.
- The periodical maintenance required for the cryocooler, every one to two years, has been a major concern.
- The necessary upgrade of the targetry system needs to cover not only basic subsystems like the beam dump and target but also ancillary systems like non-conventional utility and remote handling. Such upgrades often demand comprehensive planning and strategic deployments to avoid extended downtime.
- An integrated machine protection system for the RIBF facility needs to include the targetry system with carefully tested sensors, integrated controls, and prompt interlocking and beam inhibit. The suggested run permit system should also cover targetry configuration management.
- Modern superconducting accelerator facilities often use a centralized high-efficiency helium liquefaction system with segmented cryo-distribution supplying cryogen to both accelerator and instrument devices. Such practice ensures high energy efficiency, minimum cryogen loss, and reduction of excessive maintenance associated with distributed cryo-coolers.

Recommendations:

- The NCAC recommends to ensure the inclusion of the targetry system in the overall facility upgrade plan covering beam dump and target as well as machine protection and ancillary systems.
- The NCAC recommends that major improvement and re-configuration of the cryogenic systems be planned using a series of cryocoolers in close cooperation with the cryocooler suppliers, in order to realize further reliable and efficient operation in the long-term future.

Instrumentation Development

Findings:

- The Self Confining RI on Target system (SCRIT), invented at RIKEN, did make progress towards first experiments. SCRIT is trapping RI ions in a potential well within the straight section of this microtron type setup.
- The team did work successfully on a two stage stacking for dc to pulse conversion and on the understanding of ion trapping and ion motion inside the SCRIT system.
- The Rare RI Ring (R3) project moved into the measurement era using the TOF method with operation of R3 at the gamma-transition. The TOF prior to injection is used as a

filter for the injected RIs. First results of R3 physics experiments have been published in 2022 (^{126}In, ^{125}Cd, ^{123}Pd).
- RUNBA would allow an increase of the luminosity for envisioned RI-RI reaction experiments by a factor of 10,000 using a recycler ring. The plan is to recover energy loss with an RF cavity and combat lateral scattering by emittance correction.

Comments:

- NCAC congratulates RNC and the SCRIT team for the worldwide first experiment of electron scattering on online produced rare isotopes, and congratulates R3 and RUNBA projects for being advanced with unique science capabilities expected.
- The increase of the SCRIT e-beam power from 20 W towards 2 kW required for the RI beam production via photofission will need to focus on the development of the RI target ion source and on the radiation protection side.
- The RUNBA concept is very interesting but also extremely challenging in terms of beam emittance and charge-state issues, for example - feasibility studies would be beneficial.
- The provision to use RIs produced by RIBF and decelerated by a gas stopping cell was not mentioned, but is foreseen for the long term future of the SCRIT and RUNBA facilities after the upgrade of RIBF.
- The next step of using an EBIS to trap RI ions needs to be carefully investigated. It allows to establish a strong space charge trapping potential independent of the role of the electron beam circulating in the ring, but the magnetic field has influence on the electrons circulating in SCRIT.
- A long list of development activities has been presented, which was not prioritized and no timeline was given. The potential impact on resources available for the RIBF upgrade project did not become clear.
- There is involvement of many collaborators in the facility operation and development, which should be utilized for the planned activities.

Recommendations:

- The NCAC recommends that activities on SCRIT and RUNBA planned for the next mid- to long-term plan period be reviewed in terms of potential impact on resources required for RIBF operation and the planned upgrade.

IV. Nuclear Science Research Division

Nuclear Structure & SHE

Findings:

- Experimental research on exotic nuclei at RIBF is performed by three groups with the goal to arrive at a unified picture of the nucleon many-body system and a nuclear physics view of the Universe.
- The HiCARI experimental campaign was impacted by COVID-19 in that experiments requiring the MINOS target could not be operated due to the experts from the French home institution unable to travel to Japan.
- The instrumentation development has allowed a new generation of experiments with SπRIT, R3 and OEDO.
- The optimum use of the beam time is achieved with parallel experiments made possible with the MR-TOF-MS system installed at the end of ZDS.
- So far, a total of 462 days were spent in the search for element 119 in the reaction ^{51}V + ^{248}Cm.
- In order to choose the correct beam energy the quasi-elastic barrier distribution of the reaction ^{51}V + ^{248}Cm was measured.
- The combination of GARIS-III and MR-TOF resulted in the mass measurement of a first superheavy element (^{257}Db).

Comments:

- In spite of the difficulty induced by COVID restrictions in 2020-2021, the harvest of data over the last years is impressive and has shown that nuclear structure far away from stability is an inexhaustible source of surprises.
- The NCAC congratulates the teams for their impactful accomplishments including
    - new isotope discoveries on the neutron-rich and neutron-deficient side of the nuclear chart,
    - the study of the magicity of the key nuclei ^{78}Ni and ^{28}O and exploration of the neutron magicity from N=34 to N=40,
    - the observation of multi-neutron correlations beyond the neutron dripline, culminating in the discovery of a “tetra-neutron-like” 4-neutron correlation in the alpha removal from ^{8}He,
    - the first results from SπRIT on the symmetry energy of the EOS from charged-pion ratios, and
    - the pioneering decay spectroscopy, mass measurements, and neutron capture surrogates for r-process studies.
- The experimental group continues to attract international collaborations who bring their state-of-the art detection systems for successful experimental campaigns. This is an important part of the success of the research program at RIBF.

- The NCAC is looking forward to future programs using the new collaborative detection systems NEBULA-PLUS+HIME, Strasse+CATANA+, and TOGAXSI and RIBF's own ZD MRTOF MS system and the Rare RI Ring which now appear ready for routine use.
- The NCAC was informed that the choice of the reaction $^{51}V + ^{248}Cm$ was driven more out of availability of beam and target material and not purely by scientific arguments. The reaction $^{50}Ti + ^{249}Bk$ is probably the more promising synthesis reaction in terms of the production cross sections due to the fact that ^{50}Ti is closer to doubly magic ^{48}Ca than ^{51}V. Furthermore, the use of odd proton projectiles has so far considerably lowered the production cross sections.
- The NCAC is looking forward to the limits on the cross section for Z=119 that will be set by GARIS III.
- It is essential for the facility to reduce the backlog of experiments in the short term, and to ensure a prolific experimental program in the medium and long term.

Recommendations:

- The NCAC recommends that RNC management take all necessary actions enabling a significant increase of beamtime for RIBF.
- If no event is observed for Z=119 at 5 fb, the NCAC recommends that the team evaluate and eventually reconsider the experimental strategy before taking additional beam time.

Nuclear Astrophysics

Findings:

- Experiments at RIBF and their analysis generate knowledge about nuclear structure and reaction rate properties in isotope regions away from stability.
- The X-ray astrophysics group activities resulted in key hardware contributions to several current (and near-future) space missions in astrophysics. The group has established itself as a member within the MAXI, IXPE, and NICER missions, as well as in the future XRISM mission, focusing on new and advanced detectors and their calibration and response. Recent results include the findings of quenching of an atmosphere near the surface of a highly-magnetized neutron star and unique vacuum behavior in extremely strong magnetic fields. The XRISM mission promises X-ray signatures from a large variety of elements, and thus will provide new insights from nucleosynthesis signatures in hot intergalactic and interstellar plasma. The development of novel gamma-ray telescope techniques based on gamma-ray concentration optics has potential to advance sensitivities by several orders of magnitude compared to presently-available instruments, extending this astronomical window to individual faint sources in our Milky Way and to extragalactic sources.
- The Astro-Glaciology group has successfully advanced their unique world-leading Laser Ice Melting device, which now achieves a resolution better than one year in the record from a few-100,000 years before present. This device appears now ready for targeting the intended supernova event searches out to ~ a million years before present. As an

aside and spinoff, results on the history of solar activity and the Earth's atmosphere are obtained; these correlate to climate changes, and thus provide results relevant for current societal issues, which earth science cannot do with the accuracy level and time range of the Astro-Glaciology group.

Comments:

- The fundamental nuclear physics projects motivated by astrophysics are impressive in their success and world-leading scientific results. This is particularly relevant for the astrophysical r-process that is expected to happen in explosive environments such as supernovae and neutron star mergers.
- Satellite observation of high-energy bodies for which the X-ray Astrophysics group of RNC have provided devices can reveal various new physics in extreme conditions, which will give important information to experimental and theoretical physics in RIKEN.
- Collaboration of the X-ray Astrophysics group and experimental and theoretical groups in RIKEN will contribute to the understanding of nuclear physics in the cosmos. The NCAC sees opportunity in expanding the X-ray astrophysics studies by collaborating with other groups within and outside of RIKEN to achieve a fundamental understanding of nuclear physics in extreme conditions such as the neutron star surface. It also recommends strengthening spectroscopic studies to obtain information about nucleosynthesis.
- The NCAC sees opportunities for the X-ray Astrophysics group to obtain detailed information about nucleosynthesis in nearby galaxies with X-ray spectroscopy and encourages to pursue such opportunities.
- The precise information about activity of the Sun by the Astro-Glaciology lab allows to determine the supernova explosion rate in the vicinity of the solar system across the recent million years with a highly precise absolute age, which neither astronomical nor other methods by earth sciences can provide.
- The Astro-Glaciological research in collaboration with solar and Earth science will contribute to social issues including solar activity and environmental change, and thus can be an additional contribution by RIKEN to society.
- The NCAC sees opportunity in the Astro-Glaciology group to strengthen collaborations with the field of solar science and Earth sciences to get a comprehensive understanding about societal issues including environmental and climatic changes.
- Both X-ray Astrophysics and Astro-Glaciology groups are fairly small and their planned programs seem very ambitious in light of their size and budget.

Recommendations:

- The NCAC recommends connecting the astrophysical research projects within RNC more strongly to nuclear processes in matter extremes and to r-process nucleosynthesis in astrophysical objects.

- The NCAC recommends establishing a regular (annual) coordination of astrophysical projects & groups at RNC and RIKEN, including RIKEN pioneering research and chief scientist groups, the RNC astrophysics groups, and possibly external scientists.
- The NCAC recommends that the Astro-Glaciology Laboratory group be resourced to maximize utilization of their unique laser melting device to achieve outstanding scientific results.

Theory

Findings:

- The RNC theory groups are playing a leading role in few- and many-body systems and in guiding new developments at RIBF, with excellent scientific accomplishments in few-nucleon systems, hypernuclei, cluster structures, density functional theory for nuclei, and fusion reactions. Recent highlights of the theory groups include studies of multi-neutron correlations, predictions of new hypernuclei, and fusion reactions of astrophysical interest.
- The expansion with the new nuclear many-body theory laboratory of Kimura is an excellent addition to the few-body systems laboratory of Hiyama. The joint appointment of Hiyama is also an excellent setup.
- The theory efforts are well aligned with the TRIP concept and well connected to iTHEMS. Highlights include the extension of few-body expansion methods to 10 particle systems, utilizing neural networks to train nuclear reaction calculations, and using quantum computing for large-scale nuclear shell model calculations.
- Both theory groups are now located in proximity at the RIBF building, which maximizes interactions and is building a joint theory effort.

Comments:

- The NCAC congratulates RNC to the new theory hire Kimura.
- The NCAC continues to be concerned about a critical size of the RNC theory effort. At present, this includes two PIs (one of which is part time) and one permanent researcher, compared to the past 6 permanent researchers. A strategic hiring plan is needed to develop a broad and internationally highly competitive nuclear theory program.
- While the world-leading RIBF is opening outstanding opportunities for theory, there will be strong competition from the upcoming international rare isotope beam facilities. For both, strong leadership in nuclear theory at RIBF is critical, to maximize the science return and for future planning at RIBF.
- Adequate support of HPC resources are critical for a successful nuclear theory effort at RNC.
- The connections to TRIP and iTHEMS can be strengthened further by strategic hires.
- After the new hire, developing a nuclear theory network/platform that connects to the universities is important. A seed for this can be the newly started Nuclear Theory Promotion Forum.

Recommendations:

- The NCAC strongly recommends the hire of a permanent researcher in the nuclear many-body theory laboratory working on modern nuclear theory, such as ab initio calculations of medium-heavy nuclei. For the long term, the NCAC also recommends expanding the theory group to its previous size of permanent positions, to provide support and intellectual guidance for the present and future RIBF programs.
- The NCAC recommends building a theory platform to connect to the nuclear theory efforts in Japan and internationally. In order to strengthen university connections in Japan, the NCAC also recommends emulating the highly successful RIKEN-BNL theory fellow program to seed new faculty positions in theory at universities and to explore joint appointments in strong cases.

Sub-nuclear physics

Findings:

- The RIKEN center at RAL-ISIS has been brought to a successful conclusion, leading to over 500 publications in the course of its operation.
- RBRC, the RIKEN center at BNL, continues with the signing of the MOU for the years 2023-2028. RBRC remains a model for international collaboration with a flourishing research output. Scientific highlights include the most precise determination of the gluon polarization by the PHENIX experiment, lattice QCD calculation of the muon anomalous magnetic moment, and the successful startup of the sPHENIX detector.

Comments

- The RIKEN-RAL center leaves a strong legacy in the UK.
- The muon program at J-PARC has been initiated and the research programs on deeply bound pionic atoms at RIBF and kaonic nuclei at J-PARC have achieved great successes.
- With the decision by US DOE to realize the EIC at the existing RHIC accelerator at BNL, there is a real opportunity for RIKEN to leverage considerable previous investments by playing a leadership role in coordinating the EIC-Japan participation in the EIC project detector.
- After the closure of Meson Science Lab in JFY2023, RNC will lose the research group which have promoted sub-nuclear physics programs at J-PARC and RAL.
- While promoting cutting-edge nuclear physics research using the RI beams at RIBF, efforts should be made to ensure that sub-nuclear physics research, an important field of nuclear physics which requires collaboration with accelerator facilities outside RIBF, does not disappear completely from RNC.
- NCAC sees opportunities for RBRC to align with TRIP, e.g. in advanced computation.

Recommendations:

- The NCAC recommends that the RNC organize an effective EIC-Japan collaboration in the ePIC detector collaboration around the existing RBRC.

V. Accelerator Applications Research Division

Nuclear Transmutation

Findings:

- Nuclear transmutation is one of the proposed use cases of TRIP. Nuclear transmutation with high-intensity accelerators is expected to reduce the high-level radioactive waste, and to recycle precious resources such as rare-earth materials in future.
- The main mission of this group will be the data collection and R&Ds of elemental technology related to the high-power accelerators and nuclear transmutation-related technologies that can be implemented in society, such as the construction of helium recycling systems in Japan.
- To achieve the social implementation of nuclear transmutation, high-quality data collection in accelerator experiments and quantum and AI-guided calculations are anticipated.
- On the accelerator operation side, automated control of the accelerator and real-time analysis of the data will dramatically improve the measurement efficiency.
- Within the ImPACT project period, nuclear data related to specific nuclei with perspective for resource recycling have been collected.
- Based on the findings, the possibility of medium deep geological disposal was proposed. For this proposal nuclear data of Tc, I, Np need to be gathered.
- Accumulation of Nuclear data related to Long Lived Fission Products (LLFP) is continued and the data of minor actinides (Np-237) is to be accumulated, and the secondary beam experiment @ RIBF is to be realized in near future.
- Technical approaches towards a 1-amp class linac have been shown. A test set-up for an ion source in collaboration with NIFS, beam halo generation and solutions for the large aperture SC cavities have been presented.
- Design study on high beta superconducting cavities is ongoing in cooperation with industry.

Comments:

- The results achieved in the ImPACT project period are very much commended.

- The RNC transmutation program is moving towards data collection in the heavy mass region and it is planned to acquire funds within TRIP.
- A comprehensive plan for the design and construction of the 1-amp class facility has not been presented, but the group does focus on technical design activities, demonstrating the feasibility of key components.
- The plan for expanding RIKEN's He recycling system so that it would be able to serve communities beyond RIKEN needs to be further investigated in view of feasibility and economic viability.
- Design study on a high beta superconducting cavity with a reduced dimension (1.2 to 0.6 m in diameter) has improved the overall feasibility of the design.
- NCAC commends the team for the four patents that have been issued and registered and which originated from R&D within the ImPACT project.

Recommendations:

- The NCAC recommends that a comprehensive plan for the design and construction of a 1-ampere class transmutation linac facility will be developed, ensuring a feasible SRF cavity design, and including an economical solution for He recycling.

Ion Beam Breeding

Findings:

- The Ion Beam Breeding group continues to study and apply heavy ion irradiation for DNA mutations in biological systems mainly terrestrial food, ornamental and biofuel crops, but also marine plants and microbes.
- Optimal linear energy transfer for mutation induction and the generation of useful plant mutants were described in a model plant species and two major crop species.
- An Automated Mutation Analysis Pipeline established recently has led to the characterization of the nature of DNA mutations from ion beams of C (30 keV/μm) and Ar (290 keV/μm) at the whole genome level.
- Based on the nature of mutations identified between the different ion beams tested, the group proposes to provide 'tailor-made suggestions' for desirable plant traits, at a broad level, ie., simple versus complex traits.
- Gene editing is applied for research purposes for the validation of mutations.
- A total of 39 varieties generated from ion beam irradiation are now on the market.
- A good list of international publications has contributed to global knowledge exchange on the use and application of ion beam breeding.
- Overall budget has seen a decline from 2018 to 2022.

Comments:

- The group is strongly commended for its efforts and positioning as a global leader in investigating and sharing the use and applications of ion beam radiation in breeding.

- Generation and use of big data from mutational instances of ion beam breeding for determination of genetic associations and predictive breeding is a clear fit to the aim of the TRIP concept of societal transformation in the face of current and foreseen global challenges.
- Characterization of the nature of mutations from different LET ion beams has provided a basis to tailor mutations at the broad level, specifically, simple vs complex traits.
- A good array of beneficial mutations has been generated in plant and microbial species, though the analysis and establishment of genetic associations remains limited to a few instances.
- Incorporation of CRISPR-Cas9 gene editing as a research tool for validation of mutations places the team's work alongside current frontline research in plant biotechnology. It is cautioned, though, that gene editing is not used towards commercial variety development without securing necessary license from patent owners of the CRISPR-Cas9 technology.
- The group is also commended for the continued efforts to serve as a hub for ion beam breeding research for a large number of national and international collaborators and its contribution to the application of ion beam irradiation for the generation of useful rice varieties in at least one country in the Asia Pacific region.

Recommendations:

- The NCAC recommends ion beam breeding as a use case study for TRIP with the use of genomic and phenomic big data for genetic associations and predictive breeding.
- Enhanced exploration of different LET ion beams for the generation of different types of DNA mutations for simple and complex traits is recommended.

Nuclear Chemistry

Findings:

- The nuclear chemistry group is active in the fields of superheavy element research and radioisotope production for different applications, but notably in the field of medical isotopes.
- For this purpose the following accelerators are being actively used: AVF cyclotron (beams of p, d, α, and heavy ions), RILAC for beams of ^{18}O to ^{70}Zn, most notably ^{51}V for the synthesis of E119 and the RIKEN ring cyclotron (high energy beams of ^{14}N).
- Several specialized laboratories for the handling of highly radioactive materials are available (including the handling of actinide materials such as ^{248}Cm).
- The group is collaborating with a large number of national and international research groups, thereby playing an important role as local host in the use of the RIKEN accelerator complex.
- A very important activity, which was highly appreciated by national collaborators, was the development of a regular supply of the alpha-particle emitter ^{211}At for future applications in targeted alpha therapy (TAT).

- Preparations for the production of ^{225}Ac in the reaction ^{226}Ra(p, 2n) are underway.
- In superheavy element research (apart from the attempts to synthesize the new element with atomic number 119, which are being discussed separately) the decay properties of ^{266}Bh were investigated in more detail. The decay properties of this nuclide are essential as it constitutes a decay member in the decay chain of ^{278}Nh.
- Two superheavy element chemistry experiments were concerned with the behavior of Rf, *Z*=104 (reversed-phase TTA extraction of fluoride complexes of Rf and hydroxide co-precipitation of Rf, both in relation to the chemical behavior of the lighter homologs of group 4).
- Plans for the future involve the development and implementation of a large scale production technology of ^{211}At using the upgraded SRILAC, which will provide significantly higher beam intensities. This will enable the supply of larger amounts of ^{211}At to collaborators and ultimately to supply all phases of clinical trials. A patent was submitted related to this activity and cooperation with an industrial partner was started.
- On the agenda is also the development of the production of ^{225}Ac, an extremely important radioisotope in TAT. Plans in superheavy element research involve the use of GARIS-III as pre-separator for chemistry experiments such as solvent extraction of Sg and Bh. No aqueous chemistry experiments with direct detection of the separated nuclide have ever been performed so far. The connection of an RF carpet gas cell will enable future gas chromatographic experiments with superheavy elements or chemical investigations in an ion trap.

Comments:

- The group has achieved an impressive amount of high-quality research and excels at the number of international publications, especially considering the size of the group.
- The activities in radioisotope production should be regarded as extremely important for RIKEN as an enabler of basic and applied research in fields other than nuclear physics and chemistry, notably cancer research! Managing the intellectual property rights with diligence is critical to maximize the long-term benefit to RIKEN from these developments.
- In no way underestimated should be the contributions of nuclear chemistry technologies to other in-house experiments conducted at RIKEN. These contributions consume a substantial amount of work and are absolutely essential, while immediate results for the group are not always readily visible.
- Since the project to develop ^{225}Ac production involves the handling of significant amounts of highly radioactive ^{226}Ra as target material, this task is very ambitious.
- Newest developments point into the direction of “theranostics”, meaning a combination of diagnosis and therapy with the same active pharmaceutical compound. Internationally, the application of radiopharmaceuticals in diagnosis and therapy is rapidly increasing and predicted to generate revenue of several tens of billions dollars per year.
- The way from radioisotope to radiopharmaceutical suitable for human application is long and tedious. Often, hospitals with nuclear medicine wards are not equipped and not

qualified to synthesize radiopharmaceuticals in a GMP compliant manner. In order to supply clinical trials RIKEN might consider establishing a centralized GMP compliant radiopharmacy to significantly accelerate clinical research.
- Utilizing RI's for medical purposes produced by an accelerator, requires significant research efforts based on radiochemistry. Therefore, the group requires more radiochemical staff.
- The research in superheavy element chemistry is at the forefront of the field.
- The use of GARIS-III as a pre-separator for nuclear chemistry experiments is highly endorsed in pushing superheavy element chemistry to higher atomic numbers.
- The high intensity alpha-particle beams available at the RNC could be used for the production of additional radioisotopes, e.g. metallic radioisotopes for positron emission tomography.

Recommendations:

- It is recommended that the protection and management of intellectual property generated in the field of medical isotopes is monitored closely.
- It is recommended that RIKEN takes advantage of its unique capabilities to deliver high intensity alpha-particle beams to produce and distribute additional radioisotopes.

Industrial Applications

Findings:

- The RCN irradiation facility is used for tests of electronic components that are dedicated to application in space exploration.
- Single Event Effects (SEEs) caused by high LET(dE/dX) cosmic rays are simulated and required to achieve the certification for space agency use.
- Irradiations at the RNC will demonstrate the required performance of the electronics under the typical irradiation levels in space.
- The facility allows a beam painting of a homogeneous distribution over a 5 cm beam spot using an x,y wobbler magnet and irradiation can be done with the device in atmosphere.
- Higher-LET and longer-range beams are requested, which require beam development with heavier elements like Xe, Au or Bi.

Comments:

- The requests to use the facility are increasing rapidly. The fee is not representing the real costs, but it is not clear how the value per hour has been determined.
- The exploitation of the facility is recommended and is a demonstration of the application of a nuclear physics facility for societal benefit and does fit into the TRIP concept.

Recommendations:

- None

VI. Scientific Strategy and Management Policy Plan

General Research Strategy

Findings:

- New vision statements towards 2030 were formulated, which emphasizes the embedding of frontier research at RIKEN with societal goals and issues, responding to these. Carrying the achievements of fundamental and cutting-edge science towards industry and society is stated as the overarching goal. This shall be done by utilizing RIKEN's strengths and in innovative flexibility, employing international talent diversity. Industrial applications and response to societal needs are an explicit goal.
- The RNC's science goals for the 5th Mid- to Long-Term Plan period are stated in two main questions "How were the elements created by the universe?" and "Can humans change the elements at will?". The main elements of the RNC strategy for the next mid- to long term plan are focussed on the RIBF upgrade and the execution of the current TRIP use case on nuclear transmutation and the development of additional use cases.

Comments:

- The two main RNC science questions characterize well the various projects pursued in the RNC, and also serve as visional statements for the various PI groups.
- Overall, the RNC responds to the threats and weaknesses identified in the SWOT analysis as well as the opportunity through the overarching RIKEN objectives in a very effective manner. The resulting strategy is building on the RNC's strengths and is putting forward the RIBF upgrade as its main element while also advancing the radioisotope deliveries to medical applications, the ion beam breeding program and other industry applications like irradiation of semiconductor components, as well as the nuclear transmutation activities. The NCAC strongly supports this overall strategy.
- The RNC is well positioned to continue carrying out world-leading nuclear science research across its whole portfolio. The RIBF upgrade is critical to achieve this.
- The RIKEN TRIP strategy has been successfully implemented at RNC's Nuclear Transmutation projects.

Recommendations:

- None

Transformative Research Innovation Platform (TRIP) of RIKEN Platforms

Findings:

- Transformative Research Innovation Platform (TRIP) is a bold, new research strategy aimed at linking together RIKEN's leading-edge platforms to develop innovative technologies towards realizing a green, sustainable society for Japan and the world. There are three aspects of 'DX', 'AI', and 'quantum computing' to the broad concept:
    - Generation of high-quality data
    - Discovery of new theoretical frameworks to understand and use the data
    - Development of innovative computational techniques to carry out both effective analysis of the data and detailed simulations.
- The TRIP goal is to pioneer a new, predictive control across fields of science relevant to addressing social and global issues.
- The RNC has one ongoing TRIP use case focussed on Prediction and Control of Nuclear Transmutation which involves an experimental part related to obtaining high quality nuclear data and a theoretical part focussed on high-precision of nuclear structure and reactions.

Comments:

- The NCAC supports this bold, new vision of RIKEN on the 2030 Horizon. The TRIP concept aligns well with the research paradigm used for decades in subatomic physics by the RNC, which includes.
    - acquisition of high-quality data relevant to understanding the structure and properties of subatomic systems are generated using large accelerators,
    - continuous development and refinement of theoretical frameworks to explain previous data as well as making predictions of new phenomena that motivate further experiments;
    - development of ever-increasing powerful computers is driven by the demands to effectively analyze the experiments, to make theoretical predictions, to carry out detailed simulations, and to compare these to experimental data in order to extract new scientific insights; and
    - driving subatomic physics-based innovations both in Artificial Intelligence and in the quest to realize a Quantum Computer.
- The challenges in engaging the RNC in TRIP more broadly include:
    - defining at a high level the societal and global issues that RIKEN chooses to address;
    - engaging with the RNC to develop a scope of work that utilizes their unique expertise in experiment, theory and computation to address any issue in an effective way with clear, mutually agreed goals, milestones and schedules;
    - discriminating between tests of specific scientific models or hypotheses on data, and the AI approach to capture information from data; and

    - taking care that the careers of young subatomic scientists who work on the research within the TRIP concept are mentored and supported.
- The NCAC commends the RNC for establishing a TRIP use case with a focus on Nuclear Transmutation.
- The NCAC sees additional opportunities to develop new TRIP initiatives around several avenues such as
    - furthering the existing science goals of the RNC program, e.g. around ion-beam breeding or medical isotope applications;
    - utilizing AI/DX for sustainability and energy efficiency improvement, and maximizing the accelerator performance in the future/upgrade programs; or
    - utilizing advanced superconducting RF technology for QC, or radiation effects testing with beams to develop resilience of QC devices against coherence loss through cosmic radiation.

Recommendations:

- The NCAC recommends that RNC vigorously pursue opportunities to develop additional TRIP activities.

RIBF Upgrade

Findings:

- The challenge in the next decades is heavy element RI, with three pillars of 1) Nuclear Force (Three-nucleon forces), 2) Resonances and continuum, and 3) Heavy RI physics, requiring instrumentation for ‘high power RI beam production’, ‘high-purity RI beam separation’, and ‘platforms for reaction studies’.
- The RIBF Upgrade would increase the U beam intensity by a factor of 20 with an increase in power consumption by 30%.
- The current BigRIPS can accept up to 500 pnA of the ^{238}U beam. For the final goal of 2 pμA beam intensity, RNC needs to develop a new production-target system, beam dump and F1 slits.
- To deal with the ultimate beam intensity, the approach for the new target system is the use of a rotational carbon plate with a diameter of 1 m and the replacement of the existing beam dump with a drum-shaped copper-alloy-based system of about 30 cm in diameter. The drum will rotate while irradiated, but no further beam painting is foreseen.
- The team has formulated the science case for their upgrade in three pillars where the first two are strong programs carried over from the existing RIBF and the third pillar is the expansion of nuclear structure and reaction studies to heavy elements (below U) across the chart.

Comments:

- The RIBF Upgrade is an essential step to maintain leadership for the cutting edge of rare isotope science in light of worldwide competition.
- The first phase of the RIBF upgrade will focus on CSR1, on the new SC quadrupole quadruplet to increase the separation power of BigRIPS and on the existing accelerator complex to reach the higher beam intensity of 500 pnA. According to the plan RNC will not need to address the BigRIPS beam power upgrade during the first phase.
- The second phase of the upgrade will have significant impact on the accelerator infrastructure, remote handling capabilities, target and beam dump infrastructure and BigRIPS spectrometer systems.
- The strategy for the reliable supply of cryogenic cooling for the future upgrade of the SC focusing devices in BigRIPS has not been addressed.
- NCAC finds the overall science case for the RIBF compelling, with a science reach and science drivers similar to those articulated in long range plans and pursued at competitor facilities using fast uranium fragmentation beams, such as FRIB and FAIR. However, it was not clearly communicated what the upgraded RIBF unique advantage is for the study of nuclei at and beyond the proton dripline, given the decades of successful precision work with stable-beam induced fusion reactions at facilities such as Argonne National Laboratory (ANL) in the US and the upcoming capabilities at GANIL with SPIRAL2 and the S3 high acceptance spectrometer. The NCAC joins the RIBF upgrade team in finding the proposed utilization of isomeric beams for reaction studies a very interesting opportunity.
- The articulation of specific high-impact science cases will be useful to communicate better the unique advantage of the RIBF upgrade to non-expert stakeholders. This includes the exploration of extreme regions of the nuclear chart to better constrain nuclear forces in unprecedented conditions, to understand the complex interplay of structure and dynamics in the upper part of the proton dripline, and to elucidate the heavy element abundances in the universe and the termination of the r-process at the origin of their production.
- The RIBF upgrade team is commended for the visionary plans to upgrade the fragment separator and spectrometer beam lines to increase resolution in pursuit of the challenging PID of heavy nuclei.
- The advanced design of the CSR has been reviewed by a TAC, which has provided valuable recommendations for the advancement of the project. It is a very challenging design, but technically sound and ready to move into the project phase.
- A RIBF upgrade project description has been provided, but a resources loaded project plan for the next mid- to long-term plan has not been presented.

Recommendations:

- The NCAC recommends that RNC develop an integrated and phased RIBF facility upgrade resource loaded project plan including new accelerator sections, major

performance limiting systems and major infrastructures and request and allocate resources accordingly.

- The NCAC recommends that RNC develop a strong communication message to explain to high level representatives the exceptional scientific impact of the upgrade.