Recommendations

from the

1st RIKEN Center for Quantum Computing

Advisory Council

to President Makoto Gonokami

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Key learnings

We find that the RIKEN Center for Quantum Computing (RQC) has a world-class research program in both direction and execution. This program is providing a guiding light for teams around the world in the science and development of quantum computers of increasing scale and of novel systems. The wide reach of the Center's research efforts and applied science programs is already showcasing the best capabilities of Japan's research system.

Furthermore, the Center is proving to be a fertile ground for both junior and senior researchers to pursue challenging and worthwhile projects in a sustained manner. The corresponding *esprit de corps* and sense of purpose clearly drives an international cadre of scientists to perform transformation and creative research alongside stellar engineering and development work.

The RQC approach is scaling today's system, iterating tomorrow's system, and identifying the next platform to move from the science pillar to the prototype pillar. We find that for building prototype quantum computers and understanding the necessary ecosystem to enable larger-scale quantum computers, this approach enables the Center to be ahead of scientific and technical uncertainties in the future of quantum computing systems, including the physics of qubits, the scaling and integration of systems, and architecture and implementation of larger-scale devices, and the exploration of applications for quantum computers for the future of society.

Already a world leader in superconducting qubits with the 64 qubit system and strong industrial partnerships to enable the rapid development necessary to engineer these systems, the RQC is poised to execute at a similarly high level for three additional platforms: photon-based, atom-based, and spin-based quantum computers. A responsible investment in these different systems, including a series of quantum readiness levels, will enable the RQC to be a world leader in multiple major hardware platforms, and form the basis for a robust domestic

quantum computing ecosystem.

RQCAC responses on Terms of Reference (TOR 2) to RIKEN President

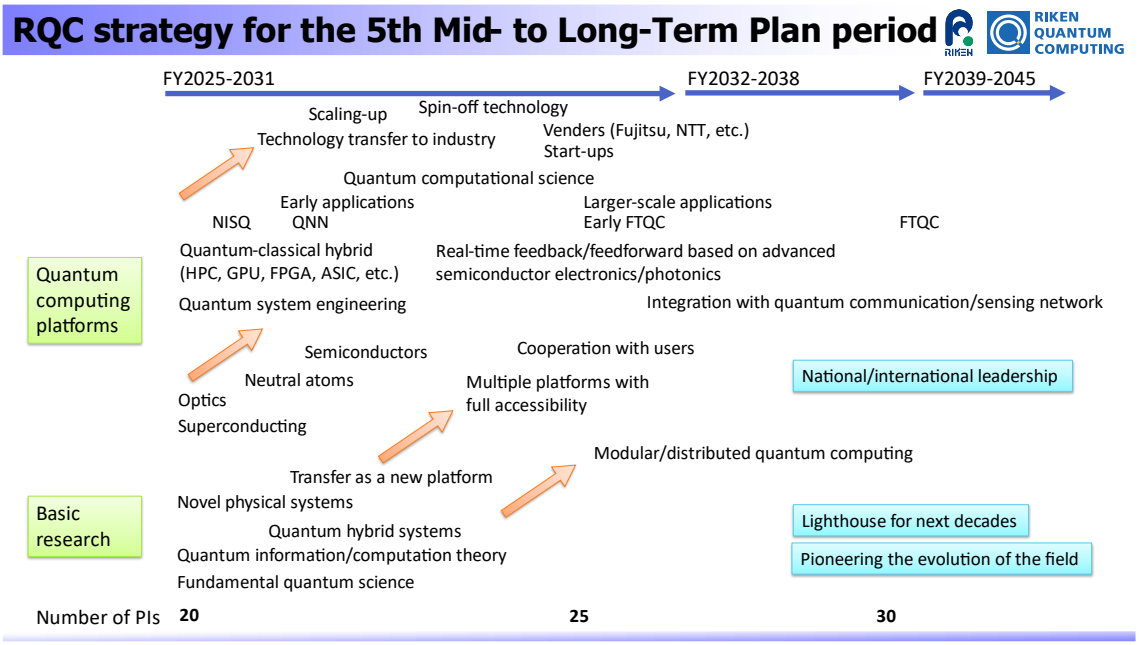
Response to Director's Terms of Reference #2; Evaluate policies of the FY25-31 period, and recommend new directions for operations and R&D that should be implemented and promoted.

RQC's future activities will center around the following two pillars.

Pillar #1: Platform of flagship gate-based quantum computing service in Japan (64-qubit superconducting quantum computer, optical quantum computer by next summer)

Pillar #2: Basic science for next or future generation quantum computer Technologies

For the RQC to take leads in the both pillars, it is important to put together center's world-leading vision and goals of quantum computer advancement for the next 20+ years. Such strong and convincing grand vision and goals of the center is absolutely needed for defining center's important and meaningful roles in RIKEN's 5th mid- to long-term plan for FY2025-2031. Therefore, we have asked RQC to put together a preliminary grand vision for the next 20+ years during our meeting and describe its next seven-year vision and plan (2025-2035) within context of the grand vision. The following is the resulting preliminary grand vision provided by Director Nakamura.



In the opinion of the members of the Council, the overall vision for 20 years is to become a central element of the future quantum computing ecosystem in Japan and the world. The RQC will be where future approaches and technologies can make their transition from laboratory scale to supercomputer scale. On that time horizon, we expect RQC to be where applications of quantum systems to problems for society are first attempted and developed. Furthermore, the future workforce for quantum computing construction and usage will be developed through both the research and development efforts at RQC, but also through their external engagements both in collaboration and as a future user facility for their testbed quantum computer systems. Consequently, a robust and varied investment in quantum computing systems covering multiple hardware approaches is essential for the execution of this vision.

Key role of the RQC in computation

The center should use today‘s computational capabilities to enable creation of scalable quantum computer and to continue to build an understanding of quantum computational advantage by testing new approaches. This builds upon two decades of continuous improvement of both classical algorithms and quantum devices. It is of great importance to develop and understand the intricacies of quantum hardware at each level of the stack, in order to enable a quantum computing ecosystem in Japan. “You do not learn how to build a car by driving a car.” In this regard industries direct engagement is crucial, particularly to develop

the nascent field of quantum systems engineering.

For building prototype quantum computers on the path to scaling, the council strongly supports the RQC approach of scaling today‘s hardware, developing and improving tomorrow‘s qubits, and identifying the next platform to move from fundamental science to prototype quantum computing. RQC just did this with the addition of the optical platform for their next, and it is clear that they can do it again in the next seven-year period with neutral atoms and/or spins in semiconductors.

RQCAC responses on Terms of Reference (TOR 1) to RIKEN President

Response to Director’s Terms of Reference #1; Based on the results of the Center’s self-analysis, evaluate operations and R&D activities for the 4th Mid- to Long-Term Plan period (FY2021-2024).

RQC’s 4th Mid- to Long-Term Plan is composed of the following three goals;

i) Advancement of quantum information science, which applies the basic principles of quantum mechanics not only to the physical layer but also to the information layer used for computation, communication, measurement, etc.
ii) Establishment of quantum information processing technology for the development of a quantum computation platform needed to solve scientific and social problems
iii) Leading international role in research and development in the field of quantum computing

In these contexts, Director Nakamura has performed Center’s self-analysis in the SWOT format. In the following, Nakamura’s (RQC) analyses are shown with the advisory committee’s (AC) evaluation.

[Strengths (internal/positive)]

(RQC analysis) Full-stack high-quality research in strong teams
(AC evaluation) The superconducting and optical quantum computing systems are truly world leading. Quantum information scientists to prompt full utilization or demonstration of such unique quantum computing machines are lacking.

Basic research related to perspective quantum computing technologies are very strong.

(RQC analysis) Diverse scientific/technical approaches
(AC evaluation) Academic freedom is ensured to exhibit creative approach.

(RQC analysis) Open research environment
(AC evaluation) Further Center's effort to promote in-person discussions among researchers belonging to different groups are strongly needed, e.g., weekly lab visits, seminars, coffee hours, etc.

(RQC analysis) Frequent RQC Colloquia and Seminars
(AC evaluation) World leading scientists are giving talks

(RQC analysis) Hiring new PIs and starting new teams
(AC evaluation) The Center has succeeded in attracting top researchers in Japan. More hirings from abroad is needed.

(RQC analysis) Collaboration center with industry
(AC evaluation) Fujitsu is committed and playing a key role towards commercialization of superconducting quantum computers. Intel and Imec are collaborating with Seigo Tarucha's group. Other companies are contributing as vendors.

(RQC analysis) Headquarters of the national innovation hubs
(AC evaluation) As the headquarter, the Center is aware of the latest developments of quantum information science and technology in Japan.

In additions to RQC analysis, as Strengths, AC identifies the presence of highly related centers within RIKEN on supercomputing, artificial intelligence, emerging materials, applied mathematics, etc. for the future collaboration towards true breakthrough.

[Weaknesses/challenges]

(RQC analysis) Limited internal base budget for personnel cost
(AC evaluation)*1 This is a universal problem in the leading research institutes. RQC was founded because there was a large governmental funding opportunity in quantum computing. Therefore, RIKEN expects RQC to support itself for the period of RQC's 4th Mid- to Long-Term Plan. However, if RQC wants to hire more personnel heading into RIKEN's 5th Mid- to Long-Term Plan period, RQC must increase its visibility and profile to establish a sustainable outlook on its external budget not only from government but also from industries.

(RQC analysis) Strong reliance on external or occasional funding
(AC evaluation) Same above (AC evaluation)*1

(RQC analysis) Scattered research spaces throughout the campus
(AC evaluation) A new building or reorganization of space within RIKEN to place RQC member labs together is strongly preferable

(RQC analysis) Limited number of full-time PIs and researchers on campus
(AC evaluation) Same above (AC evaluation)*1

(RQC analysis) Limited channels for involving students
(AC evaluation) Improving visibilities by hosting more talent attracting events and publicities

Comments and recommendations for RQC Director

Strategic level

- The strategic plan for the science pillar struck us as ambitious but appropriate
- For the prototype quantum computers, developing a set of ‘quantum readiness levels (QRLs) and checking against them for
    - Exploration of FTQC
    - Running NISQ algorithms
    - Understanding scaling constraints
    - Development of supporting classical infrastructure
    - Cloud deployment
- Investing in facilities and people as QRLs are progressed.
- Growth to 25 PIs is important for expanding the leadership role of RQC in the world.
- If there is a long-term goal to having foreign researchers invest in a career at RIKEN, a transparant career pathway at all levels of seniority including mentoring and external funding development is essential for importing talent.
- RQC has a number of very competent and productive senior researchers. The council members think it would benefit the center if they can be kept. In any case, they should be informed of the plans so that they can plan their research.

Challenges to address

- **Hiring** is a continuing challenge.
    - Salaries are low.
    - Promotion is not transparent, and staff are uncertain about what is next.
    - Gender is an issue – not just in hiring, but also in day-to-day interactions.
    - Collaboration with the human resource development program is highly encouraged.
        - For example, the Q-LEAP human resource development program, the NICT quantum camp, and deeper use of the Sechi Kato program

- International **profile** is good, but can also improve.
    - Host workshops and international conferences, and target attendance at key quantum computing conferences to showcase RQC to the world.
    - Continue to support the colloquium and seminar series. External-to-RIKEN engagements should have a balance of young and old, male and female, foreign and domestic.
- **Collaboration** across teams and across centers need focus, effort, and transparency. This can be addressed by co-location, enabling lab open houses, and internal dialogue with regular gatherings of staff across groups and centers led by the junior scientists and supported by senior staff.
    - Groups can host individual events on a rotating basis and should invite the community to join (UNSW approach)
    - Joint internal/external seminars (10 min + snacks + 60 min) (MIT/Harvard approach)
    - Groups should be encouraged to share resources without compromising scientific and technical goals, and be open about appropriate boundaries and usage.
    - Furthermore, continuous approaches for address language barriers (particularly English to Japanese and vice versa) and support for social engagements for new staff are important for staff well being and development.
- Equipment procurement and delivery remains bureaucratic and **slow**, which impacts junior researchers disproportionately.
- Science in jeopardy – great work today with other countries, but this is likely to be chilling, and a clear direction would be very valuable. Restrictions on use of the RQC prototype systems need to be considered.