

**Calendar No. 676**

115TH CONGRESS }  
2d Session }

SENATE

{ REPORT  
115-389 }

NATIONAL QUANTUM INITIATIVE ACT

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R E P O R T

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND  
TRANSPORTATION

ON

S. 3143



NOVEMBER 27, 2018.—Ordered to be printed

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

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### NATIONAL QUANTUM INITIATIVE ACT

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Mr. THUNE, from the Committee on Commerce, Science, and  
Transportation, submitted the following

### R E P O R T

[To accompany S. 3143]

[Including cost estimate of the Congressional Budget Office]

The Committee on Commerce, Science, and Transportation, to which was referred the bill (S. 3143) to provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States, having considered the same, reports favorably thereon with an amendment (in the nature of a substitute) and recommends that the bill (as amended) do pass.

#### PURPOSE OF THE BILL

The purpose of S. 3143, as reported, is to provide for a coordinated Federal program to accelerate quantum research and development for the economic and national security of the United States.

#### BACKGROUND AND NEEDS

Quantum physics involves the unique behavior of subatomic particles, such as photons and electrons, that can operate in multiple states at once, displaying properties known as “superposition” and “entanglement.”<sup>1</sup> Quantum information science (QIS) is the study of the application of quantum physics to acquire, store, transmit, and process information in ways that greatly exceed existing capabilities in the areas of next generation computing, information processing, and measurement. In computing, for example, standard computer code uses a binary system of a series of ones and zeros, but quantum computer code uses units of information called qubits

<sup>1</sup>Information Technology and Innovation Foundation, “ITIF Technology Explainer: What Is Quantum Computing?,” September 20, 2018.

(or quantum bits) that can effectively be a one or a zero simultaneously in a way that exponentially increases computing speed and information storage.<sup>2</sup>

#### TECHNOLOGIES AND APPLICATIONS

QIS is expected to create new economic opportunities and growth in industries like cybersecurity, communications, transportation, financial services, and medicine. QIS is also expected to substantially impact national security by creating powerful decoding capabilities and enabling completely secure networks and communications. QIS technologies can be divided into the following three application areas:

- Sensing and metrology (e.g., precision navigation and timekeeping, and locating mineral deposits).
- Communications (e.g., secure data transmission and storage, and quantum key generation for encryption).
- Computing (e.g., performing computations much faster than existing high-performance computers).

#### INVESTMENT IN QUANTUM

Foreign governments have started to invest significantly in QIS research and development (R&D). For example, the European Union (EU) established a \$1.1 billion, 10-year, Quantum Technologies Flagship initiative to commercialize the EU's investment and expand its scientific leadership in QIS R&D.<sup>3</sup> China designated QIS research as one of four “megaprojects” in its 15-year science and technology development plan for 2006–2020, with estimated annual funding at \$244 million.<sup>4</sup> Similarly, the United Kingdom established a \$440 million, 5-year, National Quantum Technologies Program in 2013 to translate QIS R&D into commercial technologies.<sup>5</sup>

Although the U.S. Government has invested in QIS R&D for many years, starting with National Institute of Standards and Technology (NIST) and Department of Defense (DOD) workshops in the 1990s, it had not yet explicitly made quantum a national priority, stated any formal Federal R&D goals, or established a national quantum initiative or agenda prior to introduction of S. 3143.<sup>6</sup> The overall annual Federal budget for QIS R&D is difficult to calculate across the relevant departments and agencies receiving such funding, which include DOD, the Department of Energy (DOE), NIST, and the National Science Foundation (NSF). But, some analyses put the total figure between \$200 million and \$250 million.<sup>7</sup> Both NSF and NIST currently spend around \$30 million per year on quantum-related research and activities.

In June 2018, the White House Office of Science and Technology Policy's (OSTP's) National Science and Technology Council (NSTC) chartered the Subcommittee on Quantum Information Science to coordinate Federal R&D in QIS and related technologies, in line

<sup>2</sup>Id at 1.

<sup>3</sup>Congressional Research Service, “Federal Quantum Information Science: An Overview,” July 2, 2018. (<http://www.crs.gov/Reports/IF10872?source=search&guid=edbc213359c64da79320209421c07ba0&index=0>).

<sup>4</sup>Id at 1.

<sup>5</sup>Id at 1.

<sup>6</sup>Id at 1.

<sup>7</sup>Id at 1.

with the subcommittee that would be established under S. 3143. The NSTC-chartered subcommittee established under S. 3143 would create a national QIS agenda, address U.S. economic and national security concerns related to QIS, and coordinate Federal QIS policies. In September 2018, OSTP also released a National Strategic Overview for Quantum Information Science and held a White House Summit on Advancing American Leadership in QIS. The National Strategic Overview identifies policy opportunities to advance the field and paves the way toward a National Strategic Plan that will help maintain U.S. leadership in QIS. The National Strategic Overview is intended to be used by industry experts and Federal agencies to guide R&D and commercialization efforts.

In August 2018, NSF awarded \$15 million over 5 years to a multi-institution effort, in line with S. 3143, to accelerate the development of a practical quantum computer. In addition, in September 2018, NIST established a consortium focused on quantum science and engineering to support the development of the quantum industry, also in line with activity that would be authorized in S. 3143.

There has been concern among U.S. scientists, industry representatives, and Federal agency leaders that QIS is at a tipping point, that the lack of a unified national policy for QIS may hurt R&D efforts in the long run, and that current academic education and workforce training are insufficient for continued progress in QIS R&D.

#### SUMMARY OF PROVISIONS

If enacted, S. 3143 would do the following:

- Establish a coordinated 10-year National Quantum Initiative Program to accelerate quantum R&D.
- Codify a new interagency NSTC subcommittee on QIS.
- Establish a National Quantum Coordination Office at OSTP to oversee interagency coordination, provide strategic planning support, serve as a central point of contact for stakeholders, conduct outreach, and promote commercialization of Federal research by the private sector.
- Establish a National Quantum Initiative Advisory Committee to provide advice and information on a variety of QIS and technology matters and concerns.
- Codify a NIST-established quantum consortium and authorize \$60 million annually for quantum activities at NIST for fiscal years (FYs) 2019–2023.
- Authorize a QIS basic research and education program at NSF.
- Establish up to five multidisciplinary research and education centers at NSF, including an authorization per center of \$10 million per year for FYs 2019–2023.
- Encourage U.S. high-tech companies and startups to contribute knowledge and resources to a national effort.

#### LEGISLATIVE HISTORY

S. 3143 was introduced on June 26, 2018, by Senator Thune (for himself and Senator Nelson) and was referred to the Committee on Commerce, Science, and Transportation of the Senate. Senators Gardner, Harris, Daines, and Rubio are additional cosponsors. On

August 1, 2018, the Committee met in open Executive Session and by voice vote ordered S. 3143 to be reported favorably with an amendment (in the nature of a substitute).

The Committee accepted an amendment in the nature of a substitute to revise the authorization of appropriations for NIST and NSF, add direction regarding additional standards development, promote access to quantum computing and communication systems to the user community, and make technical changes.

The Committee also accepted by voice vote three amendments sponsored by Senator Markey to the amendment in the nature of a substitute. The first amendment added consideration of computational research gaps as a purpose of the underlying bill. The second amendment explicitly required NSF to award grants to institutions of higher education or eligible nonprofit organizations to support the Multidisciplinary Centers for Quantum Research and Education. The third amendment made technical corrections and required OSTP to propose a coordinated interagency program budget to the Office of Management and Budget (OMB) and submit to Congress an annual program budget report.

Also on June 26, 2018, a House companion bill, H.R. 6227, was introduced by Representative Smith (for himself and Representatives Johnson, Comstock, Lipinski, Weber, Lofgren, Lucas, Esty, Rohrabacher, Bonamici, Hultgren, Beyer, Knight, Rosen, Babin, McNerney, Biggs, Tonko, Marshall, Foster, Dunn, Takano, Higgins, Hanabusa, Norman, Lesko, Schweikert, Hurd, Brooks, Posey, Loudermilk, and Abraham) and was referred to the Science, Space, and Technology Committee of the House of Representatives. Representatives DeFazio, Westerman, Cartwright, Carbajal, and Balderson are also cosponsors. That committee ordered that bill to be reported on June 27, 2018, and it passed the House of Representatives by voice vote on September 13, 2018.

#### ESTIMATED COSTS

In accordance with paragraph 11(a) of rule XXVI of the Standing Rules of the Senate and section 403 of the Congressional Budget Act of 1974, the Committee provides the following cost estimate, prepared by the Congressional Budget Office:

##### *S. 3143—National Quantum Initiative Act*

Summary: S. 3143 would establish an office and a program to advance research in quantum information science and technology applications. The bill would authorize appropriations for the National Institute of Standards and Technology (NIST) and the National Science Foundation (NSF) to carry out related activities. CBO estimates that implementing S. 3143 would cost \$450 million over the 2019–2023 period, assuming appropriation of the authorized and necessary amounts.

Enacting the bill would not affect direct spending or revenues; therefore, pay-as-you-go procedures do not apply.

CBO estimates that enacting S. 3143 would not increase net direct spending or on-budget deficits in any of the four consecutive 10-year periods beginning in 2029.

S. 3143 contains no intergovernmental or private-sector mandates as defined in the Unfunded Mandates Reform Act (UMRA).

Estimated cost to the Federal Government: The estimated budgetary effect of S. 3143 is shown in the following table. The costs of the legislation fall within budget functions 250 (science, space, and technology) and 370 (commerce and housing credit).

	By fiscal year, in millions of dollars—						
	2018	2019	2020	2021	2022	2023	2019–2023
INCREASES IN SPENDING SUBJECT TO APPROPRIATION							
National Institute of Standards and Technology:							
Authorization Level .....	0	60	60	60	60	60	300
Estimated Outlays .....	0	46	59	60	60	60	285
National Science Foundation:							
Estimated Authorization Level .....	0	50	50	50	50	50	250
Estimated Outlays .....	0	6	24	37	44	49	160
National Quantum Coordination Office:							
Estimated Authorization Level .....	0	1	1	1	1	1	5
Estimated Outlays .....	0	1	1	1	1	1	5
Total:							
Estimated Authorization Level .....	0	111	111	111	111	111	555
Estimated Outlays .....	0	53	84	98	105	110	450

Basis of estimate: For this estimate, CBO assumes the legislation will be enacted near the end of 2018 and that the authorized and necessary amounts will be appropriated in each year.

S. 3143 would authorize the appropriation of \$60 million annually over the 2019–2023 period for NIST to expand quantum research and advance commercial development of quantum applications. The bill also would direct the NSF to award grants to non-profit organizations and institutions of higher education to establish up to five quantum research and education centers, and would authorize the appropriation of \$10 million annually for each center over the 2019–2023 period. Using information from the NSF, CBO expects the agency would support five centers under the bill; thus, CBO estimates that the bill would effectively authorize appropriations totaling \$50 million annually for the NSF.

According to a Congressional Research Service report, in recent years the federal government has spent between \$200 million and \$250 million annually on quantum information science research and development.<sup>1</sup> NIST and NSF received appropriations in 2018 for such activities. Under current law, no specific sums are authorized to be appropriated to those agencies for those purposes.

S. 3143 also would direct the President to establish a national quantum coordination office to manage interagency activities and conduct public outreach. Under the bill, the office would be staffed by employees detailed from federal agencies such as NIST, the NSF, the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration, and the Office of Management and Budget. Based on programs of similar size and scope, CBO estimates that the office would require five full-time employees annually at a cost of about \$150,000 each. The bill also would establish an advisory committee of representatives from industry, academic institutions, and federal laboratories, whose travel expenses could be reimbursed. CBO estimates that such ex-

<sup>1</sup> Congressional Research Service, *Federal Quantum Information Science: An Overview* (July 2, 2018).

penses would be insignificant in any year. In total, CBO estimates that implementing those provisions would cost \$1 million annually.

Based on historical spending patterns for similar activities, CBO estimates that enacting S. 3143 would cost \$450 million over the 2019–2023 period.

Pay-As-You-Go considerations: None.

Increase in long-term direct spending and deficits: CBO estimates that enacting S. 3143 would not increase net direct spending or on-budget deficits in any of the four consecutive 10-year periods beginning in 2029.

Mandates: S. 3143 contains no intergovernmental or private-sector mandates as defined in UMRA.

Previous CBO estimate: On July 20, 2018, CBO transmitted a cost estimate for H.R. 6227, the National Quantum Initiative Act, as ordered reported by the House Committee on Science, Space, and Technology on June 27, 2018. The two bills are similar. CBO estimates that implementing H.R. 6227 would cost \$1.1 billion over the 2019–2023 period. The estimates differ because H.R. 6227 would authorize the appropriation of higher amounts for NIST and would authorize appropriations for the Department of Energy to carry out a quantum research program.

Estimate prepared by: Federal Costs: Janani Shankaran (National Science Foundation), Stephen Rabent (National Institute of Standards and Technology); Mandates: Jon Sperl.

Estimate reviewed by: Kim P. Cawley, Chief, Natural and Physical Resources Cost Estimates Unit; H. Samuel Papenfuss, Deputy Assistant Director for Budget Analysis.

#### REGULATORY IMPACT STATEMENT

In accordance with paragraph 11(b) of rule XXVI of the Standing Rules of the Senate, the Committee provides the following evaluation of the regulatory impact of the legislation, as reported:

##### NUMBER OF PERSONS COVERED

The bill would affect certain employees of Federal agencies, institutions of higher education, nonprofit organizations, and businesses that conduct QIS R&D. The bill would cover activities of institutions of higher education, principal investigators at those institutions, and other research grant recipients that are already subject to the policies and procedures of NSF and NIST as a condition of receiving an award from one of those agencies. The bill would not impose any new regulations on individuals or businesses.

##### ECONOMIC IMPACT

The bill is intended to have a positive economic impact on the U.S. economy by authorizing funding for and accelerating quantum R&D within the United States. QIS R&D has the potential to create new economic growth and opportunities across a wide variety of industries. The National Quantum Coordination Office that would be established under the bill would promote access to and early application of quantum technologies, innovations, and expertise derived from the National Quantum Initiative Program to U.S. industry, including startup companies. It also would promote access to existing quantum computing and communications systems



developed by industry, universities, and national laboratories to the general user community. Also under the bill, NIST would establish or expand collaborative ventures or consortia with other public or private sector entities for the purpose of advancing quantum science and engineering. NIST also would convene a consortium of stakeholders to discuss the future measurement, standards, cybersecurity, and other needs for supporting the development of a U.S. QIS and technology industry. Finally, the Multidisciplinary Centers for Quantum Research and Education that would be established by NSF under the bill would foster innovation by bringing together industry perspectives to quantum research and workforce development, including by leveraging industry resources and research capacity.

#### PRIVACY

The bill would have a negligible impact on the personal privacy of individuals, institutions of higher education, or nonprofit organizations who voluntarily apply to receive grants or other awards from NSF and NIST.

#### PAPERWORK

The bill would not significantly increase paperwork requirements for individuals, institutions of higher education, nonprofit organizations, or businesses that voluntarily apply to participate in any activities or grant awards sponsored by NSF or NIST. The National Quantum Initiative Advisory Committee that would be established by the bill would be required to report to Congress on a biannual basis until the advisory committee sunsets. Similarly, the bill would require NIST to transmit to Congress a report within 2 years after the date of enactment. OSTP also would be required to submit to Congress an annual National Quantum Initiative Program budget report.

#### CONGRESSIONALLY DIRECTED SPENDING

In compliance with paragraph 4(b) of rule XLIV of the Standing Rules of the Senate, the Committee provides that no provisions contained in the bill, as reported, meet the definition of congressionally directed spending items under the rule.

#### SECTION-BY-SECTION ANALYSIS

##### *Section 1. Short title.*

This section would provide that the bill may be cited as the “National Quantum Initiative Act.”

##### *Section 2. Definitions.*

This section would define the terms “Advisory Committee,” “Coordination Office,” “institution of higher education,” “Program,” “quantum information science,” and “Subcommittee.”

##### *Section 3. Purposes.*

This section would identify that the purposes of the Act are to ensure continued U.S. leadership in QIS and its technology applications by doing the following: supporting research, development,

demonstration, and application of QIS and technology; improving the interagency planning and coordination of Federal R&D of QIS and technology; maximizing the effectiveness of the Federal Government's QIS and technology R&D programs; promoting collaboration among the Government, Federal laboratories, industry, and universities; and promoting the development of standards for QIS and technology security.

*Section 101. National Quantum Initiative Program.*

This section would require the President to implement a 10-year National Quantum Initiative Program (Program) to do the following: establish the goals, priorities, and metrics for a 10-year plan to accelerate development of QIS and technology applications in the United States; invest in fundamental Federal QIS and technology research, development, and demonstration; invest in activities to develop a QIS and technology workforce pipeline; provide for interagency coordination of Federal QIS and technology research, development, and demonstration; partner with industry and academia to leverage knowledge and resources; and leverage existing Federal investments efficiently to advance program goals and objectives.

*Section 102. National Quantum Coordination Office.*

This section would require the President to establish a National Quantum Coordination Office, which would have a Director appointed by OSTP, in consultation with the Secretary of Commerce, the Director of NSF, and the Secretary of Energy. The Coordination Office would be required to do the following: provide technical and administrative support to the subcommittee established under section 103 and the advisory committee established under section 104; oversee interagency coordination of the Program; serve as the point of contact on Federal civilian QIS and technology activities for government organizations, academia, industry, and professional societies, to exchange technical and programmatic information; ensure coordination between the Multidisciplinary Centers for Quantum Research and Education established under section 302 and the National Quantum Information Science Research Centers established under section 402; conduct public outreach, including dissemination of findings and recommendations of the advisory committee, as appropriate; and promote access to and early application of the technologies, innovations, and expertise derived from Program activities to agency missions and systems across the Federal Government, and to U.S. industry, including startup companies.

This section would require that funds to carry out the activities of the National Quantum Coordination Office be made available each fiscal year by the participating agencies of the subcommittee, as determined by the Director of OSTP.

*Section 103. Subcommittee on Quantum Information Science.*

This section would require the President to establish, through NSTC, a subcommittee on QIS (Subcommittee). The membership of the Subcommittee would be required to include NIST, NSF, DOE, the National Aeronautics and Space Administration, DOD, the Office of the Director of National Intelligence, OMB, OSTP, and any other Federal agency that the President considers appropriate.

This section also would require the Subcommittee to be jointly chaired by the Director of NIST, the Director of NSF, and the Secretary of Energy.

The Subcommittee would be required to do the following: coordinate the QIS and technology research and education activities and programs of the Federal agencies; establish goals and priorities of the Program, based on identified knowledge and workforce gaps and other national needs; assess and recommend Federal infrastructure needs to support the Program; and evaluate opportunities for international cooperation with strategic allies on R&D in QIS and technology.

This section would require the Subcommittee to develop a 5-year strategic plan not later than 1 year after the date of enactment, and develop an additional 5-year strategic plan not later than 6 years after enactment, with periodic updates as appropriate to guide the activities of the Program, and to meet the goals, priorities, and anticipated outcomes of the participating agencies.

This section would require the chairs of the Subcommittee to submit the strategic plans and any updates to such plans to the President, the advisory committee established under section 104, the Committee on Commerce, Science, and Transportation of the Senate, the Committee on Energy and Natural Resources of the Senate, the Committee on Science, Space, and Technology of the House of Representatives, and other appropriate committees of Congress. It also would require the chairs to submit to those committees a report on the budget for the Program concurrent with the annual budget request.

#### *Section 104. National Quantum Initiative Advisory Committee.*

This section would require the President to establish a National Quantum Initiative Advisory Committee (Advisory Committee) consisting of members from industry, academic institutions, and Federal laboratories who are qualified to provide advice and information on QIS and technology research, development, demonstrations, education, technology transfer, commercial application, or national security and economic concerns. In selecting the members of the Advisory Committee, the President could seek and give consideration to recommendations from Congress, industry, the scientific community (including the National Academy of Sciences, scientific professional societies, and academia), the defense community, and other appropriate organizations.

This section would require the Advisory Committee to advise the President and the Subcommittee and make recommendations to be considered in reviewing and revising the Program. Specifically, the Advisory Committee would be required to provide the President and the Subcommittee with an independent assessment of the following: trends and developments in QIS and technology; progress made in implementing the Program; whether the Program activities, priorities, and technical goals developed by the Subcommittee are helping to maintain U.S. leadership in QIS and technology; the management, coordination, implementation, and activities of the Program; whether a need exists to revise the Program; whether there are opportunities for international cooperation with strategic allies on R&D in QIS and technology; and whether national secu-

rity, societal, economic, legal, and workforce concerns are adequately addressed by the Program.

This section would require the Advisory Committee to report, not less frequently than once every 2 years, to the President on the assessments and any recommendations to improve the Program. The first report would be required to be submitted not later than 6 months after the date of enactment of this Act. The Director of OSTP would be required to transmit a copy of each report under this section to the Committee on Commerce, Science, and Transportation of the Senate, the Committee on Energy and Natural Resources of the Senate, the Committee on Science, Space, and Technology of the House of Representatives, and other appropriate committees of Congress.

This section also would allow non-Federal members of the Advisory Committee to receive travel expenses, while attending meetings of the Advisory Committee or while otherwise serving at the request of the head of the Advisory Committee away from their homes or regular places of business.

#### *Section 105. Sunset.*

This section would terminate the authorities provided in this Act 11 years after its enactment. However, the President could continue the activities of the Advisory Committee if the President determines that such activities are necessary to meet national economic or national security needs.

#### *Section 201. National Institute of Standards and Technology quantum activities.*

This section would require the Director of NIST to do the following: continue to support and expand basic and applied QIS and technology R&D regarding the measurement and standards infrastructure necessary to advance commercial development of quantum applications; use existing programs to train scientists in QIS and technology to increase participation in the quantum fields; and establish or expand collaborative ventures or consortia with other public or private sector entities, including academia, National Laboratories, and industry for the purpose of advancing the field of QIS and engineering. It also would give the Director of NIST the authority to enter into and perform contracts, cooperative R&D arrangements, grants, and cooperative agreements as may be necessary in the conduct of the relevant work of NIST.

This section also would require the Director of NIST, not later than 1 year after the date of enactment, to convene a consortium of stakeholders to discuss the future measurement, standards, and cybersecurity necessary for supporting the development of a robust QIS and technology industry in the United States. The goals of the consortium would be to assess current research, evaluate research gaps, and provide recommendations on how NIST and the Program could address the research needs identified.

This section would require, not later than 2 years after the date of enactment of this Act, the Director of NIST to transmit to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a summary report containing the findings of the consortium convened under this section.

This section also would authorize annual appropriations to NIST of \$60 million for FYs 2019–2023.

*Section 301. Quantum Information Science Research and Education Programs.*

This section would require the Director of NSF to carry out a basic research and education program on QIS and engineering, including the competitive award of grants to institutions of higher education or nonprofit organizations, which may support the Multidisciplinary Centers for Quantum Research and Education established under section 302. This program would include activities that continue to support basic interdisciplinary QIS and engineering research and support human resources development in all aspects of QIS and engineering. Specifically, these activities would include using the existing programs of NSF to do the following: improve the teaching and learning of QIS and engineering at the undergraduate, graduate, and postgraduate levels; increase participation in the quantum fields, including by individuals identified in sections 33 and 34 of the Science and Engineering Equal Opportunities Act; formulate goals for QIS and engineering research and education activities to be supported by NSF; leverage the collective body of knowledge from existing QIS and engineering research and education activities; coordinate research efforts funded through existing programs across the directorates of NSF; and engage with other Federal agencies, research communities, and potential users of information produced under this section.

*Section 302. Multidisciplinary Centers for Quantum Research and Education.*

This section would require the Director of NSF to award grants to institutions of higher education or eligible nonprofit organizations (or consortia thereof as defined) to establish up to five Multidisciplinary Centers for Quantum Research and Education. The purpose of the centers would be to conduct basic research and education activities in support of the goals and priorities of the Program to continue to advance QIS and engineering; support curriculum and workforce development in QIS and engineering; and foster innovation by bringing industry perspectives to quantum research and workforce development, including by leveraging industry resources and research capacity.

This section would require an institution of higher education or an eligible nonprofit organization (or a consortium thereof) seeking funding under this section to submit an application to the Director of NSF, including at a minimum, a description of the following: how the center will work with other research institutions and industry partners to leverage expertise in quantum science, education and curriculum development, and technology transfer; how the center will promote active collaboration among researchers in multiple disciplines involved in quantum research including physics, engineering, mathematics, computer science, chemistry, and material science; how the center will support long-term and short-term workforce development in the quantum field; how the center can support an innovation ecosystem to work with industry to translate center research into applications; and a long-term plan to become self-sustaining after the expiration of NSF support.

This section would authorize the centers selected and established under this section to carry out activities for a period of 5 years, and permit an awardee to reapply for an additional, subsequent period of 5 years on a competitive, merit-reviewed basis. This section also would allow the Director of NSF to terminate an underperforming center for cause during the performance period.

This section would authorize appropriations of \$10 million per center per year to NSF for each of FYs 2019–2023. This section also would allow the Director of NSF to establish a program to provide traineeships to graduate students at U.S. institutions of higher education who are citizens of the United States and who choose to pursue masters or doctoral degrees in QIS.

#### CHANGES IN EXISTING LAW

In compliance with paragraph 12 of rule XXVI of the Standing Rules of the Senate, the Committee states that the bill as reported would make no change to existing law.

