The Interconnection of Nuclear Energy and Quantum Technology

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One might think nuclear energy and quantum technology as unrelated. One concerns power plants, uranium, and electrical grids. The other revolves around next-generation computers, ultra-precise sensors, and advanced encryption. However, both are built on the same scientific foundations: quantum physics, or the study of how matter and energy behave at the smallest scales. A nuclear reactor and a quantum computer are governed by the same physical laws. Increasingly, tools developed in one field are becoming useful to the other.

The connection already works in both directions. Nuclear science has quietly contributed to quantum computing for years. The International Atomic Energy Agency (IAEA) has highlighted how ion beams — streams of charged particles — produced by accelerators used in nuclear research are now used to manufacture quantum devices. A well-established process known as ion implantation allows scientists to place individual atoms inside materials such as silicon and diamond with extraordinary precision. Those atoms make up qubits, which are the basic units of information inside quantum processors, many times smaller and faster than traditional computer information bits. The infrastructure built for atomic research is now the basis for creating machines capable of simulating atomic behavior more accurately than ever before.

Once that connection becomes clear, the next question is obvious: what can quantum technology do for the nuclear energy industry? The answer is substantial.

Quantum Computing Can Dramatically Speed Up Nuclear Simulations

Operating a nuclear reactor safely requires understanding the behavior of neutrons inside a reactor core. Those particles collide, scatter, and are absorbed by fuel, continuously changing the temperature and pressure of the surrounding system. Since these interactions are driven by statistical processes, quality information can only be obtained through large number sampling, often around a quadrillion (or a million billions) of interactions. Suffice it to say that designing safer reactors or testing new fuels requires simulations of enormous complexity.

The primary computational method used to track neutrons is the Monte Carlo method, which tracks particles as they move through materials and interact with reactor components. The method is essential for reactor physics and the transport of radioactive materials, but it is computationally expensive. Complex simulations can take days or weeks on classical computers and still rely on approximations because no conventional machine can model the entire system directly.

Quantum computers offer a different approach to the computer application. Because they operate according to quantum principles, they can model nuclear interactions more naturally. A UK research project led by ANSWERS Software Service, part of Jacobs, alongside Oxford Quantum Circuits, the National Nuclear Laboratory, Sellafield, and the University of Cambridge, has already demonstrated that quantum algorithms can accelerate Monte Carlo simulations beyond the capabilities of classical systems. Algorithms complete in thousands of steps that calculations on conventional hardware would require millions. For an industry where regulatory approval can take years, reducing simulation times from weeks to hours could significantly alter reactor development timelines.

Both the nuclear and quantum computing fields, however, face the same obstacle: instability. Quantum computers are sensitive to environmental interference, a problem known as quantum noise. The Jacobs ANSWERS project has evaluated methods for reducing interferences on working hardware. The more stable quantum computers become, the more dependable they are for the complex calculations that reactor design demands.

Quantum Computing Can Find Better Reactor Materials

Faster simulation is only one positive aspect of quantum computing. Quantum computing may also address one of nuclear energy's most persistent challenges: materials degradation. The inside of a reactor is one of the harshest environments on Earth: extreme heat, intense radiation, and corrosive chemicals slowly degrade every component. Developing better materials traditionally requires years of testing as damage occurs at the atomic level. Engineers create samples, expose them to reactor conditions, measure the damage, and repeat the process. The cost and duration of that cycle contribute heavily to the slow development of advanced reactors, including Small Modular Reactor projects.

Quantum algorithms could shorten that process dramatically. By modelling atomic interactions under radiation and heat, quantum computers may predict how metal alloys and ceramics will behave before they are physically produced. That capability could reduce development costs and accelerate the deployment of advanced reactor designs.

Quantum Computing Can Make Nuclear Facilities Safer and More Secure

Quantum technology also has practical applications for reactor safety and security. Inside nuclear facilities, early detection is critical. Minor changes in neutron levels, temperature, or structural integrity can determine whether a problem remains in routine maintenance or indicates a larger concern. Quantum sensors, based upon quantum computing components and which can measure radiation, magnetic fields, and temperature with great precision, may provide details that aid in safety analysis.

Security is another concern. The IAEA safeguards system — the international network of inspectors, cameras, seals, and radiation detectors designed to prevent nuclear diversion — depends on securely transmitting sensitive information. Existing encryption methods may eventually become vulnerable to sufficiently advanced quantum computers. Quantum key distribution offers a potential solution. By using quantum-based systems to transmit encryption keys, the method makes interception immediately detectable. Applying it to safeguards communications would help protect nuclear security systems against future quantum-enabled threats.

Quantum Computing Makes Fusion Possible

The most consequential application of quantum technology may involve fusion power. Fusion reactors produce no long-lived radioactive waste, do not suffer from latent core overheating accidents, and rely on hydrogen fuel. Yet fusion remains elusive because plasma behavior is extraordinarily difficult to predict and control. Scientists must contain superheated plasma using complex magnetic fields while optimizing reactor conditions in real time. These are precisely the kinds of optimization problems quantum computers are expected to manage most effectively. Projects such as Commonwealth Fusion Systems and the international ITER project are pursuing fusion on timelines measured in decades. More capable quantum simulations could shorten those timelines and help solve fusion's remaining engineering challenges.

The evidence linking nuclear and quantum technologies is already substantial. Research projects, work at U.S. national laboratories, and IAEA initiatives on ion-beam technology all point toward deeper integration. What remains limited is institutional coordination.

What Remains to be Done?

Nuclear engineering and quantum computing laboratories still operate in isolation. Governments and funding agencies need programs that bridge the two disciplines. The IAEA and the Nuclear Energy Agency should also formally evaluate how quantum technologies can improve reactor safety, materials research, and safeguards systems.

Nuclear energy and quantum technology have been treated as separate fields for too long. They share the same scientific foundations, increasingly rely on the same tools, and confront the same technical problems. A future built on nuclear power will depend on quantum computing to design reactors, quantum sensors to monitor them, and quantum encryption to protect them. The institutions responsible for both technologies are only beginning to recognize how connected they already are.

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