Matteo Bucci: Using Nanotechnologies to Produce More Megawatts

What if the 450 nuclear power plants currently operating worldwide could increase their energy output by 10 percent? It would represent a significant increase in carbon-free power production and the equivalent of billions of dollars in plant operation and construction costs – and is the primary research goal of newly appointed MIT Nuclear Science and Engineering assistant professor Matteo Bucci.

The output boost would be accomplished by engineering the outer surface of reactor fuel rods using micro- and nanotechnologies, to prevent bubbles in cooling water from coalescing on the rods’ surface and forming dry patches that lead to failure. This would ensure efficient heat transfer from rod to water under a wider range of conditions, which in turn would allow reactors to run at higher power and produce more megawatts while preserving wide safety margins.
“It’s a way of getting more juice from the same lemon,” explains Bucci, who began his affiliation with MIT NSE as a visiting scientist in 2013, was named a research scientist in 2015, and won his faculty appointment in the fall of 2016. He has participated for several years in the MIT Center for Advanced Nuclear Energy Systems (CANES), which is hosting the research effort.

In signs of strong industry interest, Bucci and his project teammate, associate professor of mechanical engineering Evelyn Wang are being funded by energy giant Exelon, with fuel vendor Westinghouse Electric collaborating on the project. The support (which also covers CANES research into several other improvements to fuel rod cladding) extends for three years, and the technology could be ready for initial deployment within five years.

“The challenge is to improve economics and safety by leveraging 21st-century technology,” says Bucci, whose background in advanced diagnostics, sensors, surface engineering and heat transfer is an ideal fit for the project. “Today’s reactors were largely built with older technology, so there are many opportunities to improve their design and operation. The work is also applicable to future reactor designs, like modular small-scale light-water reactors, and the technology could also be useful in generation IV and fusion reactors.”

While exact details of the surface technologies are still confidential, the general approach is to use micro- and nano-fabrication technologies to create a porous hydrophilic outer layer on the fuel rod cladding. The efforts build on groundbreaking MIT NSE research into the effects of surface characteristics on boiling heat transfer, but will extend the initial studies, which were done at atmospheric pressures.

“Reactors are operated at much higher pressures, typically 150 bar, and boiling phenomena at those levels can be very different,” notes Bucci. “So, the next step is to develop experimental capabilities and diagnostics that can operate under the same conditions as actual reactors. This will help us shed light on the physics of boiling at high pressure, and then optimize the size and morphology of the surface features we engineer on the cladding.” MIT’s Nuclear Research Reactor will provide a rare opportunity for subsequent testing under actual reactor conditions, in cooperation with researchers Lin-Wen Hu, Gordon Kohse and Dave Carpenter at the reactor.

Bucci has already published results of a new infrared thermometry calibration technique as part of the effort, which will develop unprecedented high-resolution measurement capabilities for temperature and heat flux on boiling surfaces, with 4000-frame-per-second capture of details at a spatial scale under 100 microns.

Parallel efforts under the Exelon funding are focused on understanding and preventing CRUD deposits on fuel rods (under Michael Short, assistant professor of nuclear engineering) and averting hydrogen embrittlement (under Bilge Yildiz, associate professor of nuclear science and engineering, and materials science and engineering).

Joining the MIT NSE faculty fulfills Bucci’s desire to work in academia, following seven years as a research scientist at the French Alternative Energies and Atomic Energy Commission (CEA), which he joined after earning a master’s and doctorate in nuclear engineering from the University of Pisa in his native Italy.

“I liked the CEA environment, but MIT provides so many different possibilities, and can move so quickly,” he explains. “You hear that MIT is very competitive, but that’s not the case internally. Here, it’s MIT united against big problems, and I find it to be a very cohesive and synergistic community - faculty, students and the administrative staff.”

Bucci is scheduled to begin his teaching duties this spring, and will eventually handle Nuclear Energy Systems (22.13), Thermal Hydraulics in Power Technology (22.313) and Nuclear Systems Design Project (22.033, 22.33). He’s already had extensive exposure to MIT students, through undergraduate and graduate participation in research projects.

“It’s such a motivated and creative group of students; they understand the opportunities here, and the faculty understand that to be successful, we have to grow passion and competencies in younger people,” he observes. “The secret is to create an eco-system of people who are compatible with one another, and that’s what makes this department and MIT unique. It’s a great honor to be part of it. When I was a boy my dream was to win the Tour de France; being here is like being the Tour de France winner.”