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INTERVIEW



Ferreting out the truth about fusion: Interview with Bob Rosner

Dan Drollette Jr.

KEYWORDS Fusion; ITER; tokamak; plasma; NIF; stellarator

It's fair to say that Bob Rosner, the former chair of the *Bulletin's* Science and Security Board, is something of a skeptic when it comes to the more optimistic claims about fusion becoming a commercial energy source anytime soon. A theoretical physicist, specialist in astrophysical fluid dynamics, former president of the American Physical Society, and former director of a national laboratory, Rosner calls himself an optimist about humanity's ability to solve problems via technology (see [Figure 1](#)).

Yet this self-described plasma guy says “demonstrate to me that I’m wrong” when it comes to having a jaundiced view of some of the rosier-colored scenarios about fusion energy. At the same time, Rosner sees the possibility of strong, genuinely positive results from continuing to do fundamental research and development on fusion.

In this interview with me, Rosner delves into some of the nuances behind fusion research and what to make of them.

(Editor's note: This interview has been condensed and edited for brevity and clarity.)

Dan Drollette Jr.: As a theoretical physicist, former chairman of astrophysics at the University of Chicago, and former director of Argonne National Lab—among other things—what do you think about commercial fusion's prospects, whether it be publicly funded research at ITER¹ or private?

Bob Rosner: Let me try to answer the question in a more general way.

ITER itself is a combined science and engineering experiment. Its mission is not to achieve commercial fusion anytime soon; it's basically to demonstrate that you can reach ignition—actually get a sustained deuterium-tritium “burn” in a plasma that's hot enough and dense enough to generate some power inside a device like a tokamak.²

To some extent, that's already been demonstrated via the Joint European Torus, or JET—ITER's predecessor,



Figure 1. Robert “Bob” Rosner, former chair of the Science and Security Board of the *Bulletin of the Atomic Scientists*.

an international machine, previously the largest tokamak in the world. It did produce neutrons and alpha particles as a result of fusion, but not “ignition,” meaning self-sustaining fusion.

Drollette: If the world already had JET, then why did it need ITER?

Rosner: That goes to a crucial liability of tokamaks that still needs to be resolved.

First, a little physics background . . .

Plasmas capable of fusing hydrogen are necessarily very hot. The sun confines such hot plasma gravitationally—but we can't do that here on Earth, so we must rely on magnetic fields instead. (I'll talk about inertial fusion later.)

Traditionally, there have been three ways of confining the plasma using magnetic fields. One is what's called a “magnetic bottle,” which was the very first attempt at fusion. The idea is to orient the magnetic

field lines along a cylindrical axis, but have them bunch together at the two ends of the cylinder. The idea was that the charged particles in the plasma execute orbits that bounce back and forth between those endpoints—which is why it’s sometimes called a “mirror machine.”

The consensus ultimately was that it’s unlikely to ever really work as a reactor, so it hasn’t been pursued much further. But there’s some interest in understanding the mirroring physics better, and consequently there is a new mirror machine being built right now in South Korea as an experiment. I don’t think anybody is seriously thinking of it as an energy producer, however.

The other two variations of magnetic confinement aim to get rid of the mirrors, by basically turning the whole thing to a doughnut, or “tokamak” in Russian. The Russians invented the tokamak in the 1950s, but the design is still an incredibly good container for plasma; that’s why it’s been so popular all these years.

The other contender is something called a “stellarator.” Imagine taking a tokamak and giving it a half-twist. One big stellarator has been built in Germany (and is currently operating); another one was going to be built at Princeton, but failed—the government stopped the project.

A stellarator doesn’t have as good containment properties, but it has a few big advantages over a tokamak—and this is really the heart of the issue. Tokamaks are better at keeping plasmas hot (and are simpler), while stellarators do better at keeping plasmas stable.

The stability problem with tokamaks is due to the way they work: The magnetic fields in this doughnut shape, or “torus,” are helical, meaning spiral-shaped. The way they’re made helical is by driving a current through the plasma that’s along the axis of the torus.

The toroidal current is generated by coils sitting outside the torus; and that current—if it’s strong enough—can be unstable. Which is a tokamak’s key difficulty.

Drollette: Why?

Rosner: There’s a series of different kinds of instabilities; the most important one is called, not very imaginatively, the “disruptive instability.” A key question for tokamaks is: Can you reach ignition—sustain a fusion burn—before the plasma disrupts?

Generally speaking, tokamaks aren’t steady burners. One way to overcome that is to ramp up the current while trying to stay below the current density where you get the disruptive instability: You initiate the fusion burn, but if you sense an instability starting, you decrease the current [to where it’s more stable], then go back up and burn again—and you keep doing this. It’s a cyclic process, using feedback control to always stay below the instability threshold.

What ITER’s supposed to demonstrate is that a quasi-steady fusion burn like this can actually happen. (Laughs.) It’s never actually happened, but ITER is supposed to demonstrate it *can* happen.

That’s ITER’s basic point: ITER is done in the interests of basic science and engineering. And I think that’s great. I’m a total and complete science nerd, and if somebody is paying me money—for their own reasons—to do science, then I’m happy. That’s one reason I’m also a great supporter of NIF.³

Drollette: So ITER is about pure research?

Rosner: Yes. And what they’re really trying to achieve is a combination of fusion ignition *and* stability.

Because if a disruption happens, it’s incredibly destructive—particularly to the tokamak’s inner walls. In fact, it’s likely that if a disruptive instability ever happens at ITER, then ITER would not recover. It would be incredibly expensive to fix it, so it’s likely it wouldn’t be rebuilt if a disruptive instability occurred.

Drollette: I didn’t realize there was a risk of absolutely destroying the physical plant.

Rosner: That’s partly why it’s been so expensive; they want to make sure that doesn’t happen.

Although that’s not the primary reason for ITER’s expense: The fundamental reasons have very little to do with physics but a lot to do with international politics—science politics, especially. But that’s a separate discussion.

ITER didn’t have to be so expensive, let’s put it that way. If ITER had been organized from the beginning in a different way, more like the way CERN is, it would probably have been a very different story. But it wasn’t organized that way.

To repeat: The reasons why ITER became so expensive had nothing to do with physics or science, but with people and politics.⁴

Now, there was a competitor to the ITER design, called a “compact high-field tokamak,” which was pioneered at MIT by a person named Bruno Coppi and led to the Alcator tokamak project at MIT. His design was not chosen by ITER, but his old pals at MIT have pursued it in the form of a company called Commonwealth Fusion. They basically built on the Alcator design but included a new generation of superconducting magnets. It can get to much higher plasma densities—something that is critical for achieving fusion ignition. And the obvious question is: Will this design (or others I haven’t mentioned but are also proceeding) reach the goal—fusion ignition—before ITER?

So that explains why ITER’s being so careful, and why there’s such a big time lag. Because if they push too hard,

they might trigger an instability—and if they do that, they're done. So they're going to do everything possible to very gradually increase the current density and monitor the plasma carefully to detect any hints of instability.

Drollette: Are there other concerns?

Rosner: There are a whole bunch of issues to be answered which ITER is not designed for, if your goal is to build a commercial power reactor.

For example, a serious problem is that the neutrons that are produced [in fusion] are about 10 times more energetic than the neutrons produced in fission reactors. The most energetic neutrons are approximately 2 megavolts (MeV) in fission reactors, but because there's a moderator used in fission, those neutrons are quickly brought down in energy to a few electron-volts. That's not the case in fusion, where the neutrons' energy is roughly 14 MeV and there's no moderator. So basically the neutrons—which, being neutral, are not confined by the magnetic fields—hit the walls of the plasma chamber, causing dislocations which end up embrittling the metal of the walls. You don't want an embrittled steel casing like that—the last thing you need are cracks. So that's a problem.

Drollette: When people talk about embrittlement, are they talking about the whole structure, every which way?

Rosner: Yes, the structure. If you ever want to get a sense of how tricky it is to deal with neutrons, visit NIF and see the door to the space where the target chamber sits. It's massive, made of combined steels and concrete and god-knows-what-else; but it must be well over a meter thick. And they have to do that, because the problem with neutrons is that they're neutral—meaning that they're not so confined by magnetic fields. The best way to get rid of them is by intercepting them before they escape the place where they've been generated, so you get the neutrons to hit things like thick concrete walls where they are ultimately absorbed.

Unfortunately, you can't do that inside a tokamak—that is, protect the walls from these fast neutrons.

Drollette: There's no real solution to that?

Rosner: Well ... in theory, there is. The problem is going from theory to practice.

And that's the driver behind the huge effort in materials science to solve this embrittlement problem, by (for example) inventing what are called “self-healing materials.” Biology has succeeded in making that invention—you get a cut, it heals over. But we haven't figured out yet how to do that in the inorganic world.

We still have to figure out how to construct alloys that basically repair themselves.

Drollette: But the whole thing is still purely theoretical—we really don't know if it can be done?

Rosner: Right, it doesn't exist yet. But people are working on it, and I think there's some optimism it can be done. I can't give the details; I'm not a materials-science person, I'm a plasma guy, a fluid-dynamics person.

Drollette: Granted you're not an expert in this area, but you see self-healing materials as someday being one solution to the embrittling of reactors—maybe on a 30- or 40- year timeline?

Rosner: Yes, I think we'll have something. Embrittlement won't be a showstopper for fusion energy.

I'm an optimist—if we have a technical challenge, we'll figure out how to fix it. But that's just the technical side, not the human side, not the policy or politics sides.

Which gets us to how to pay for it all. Fusion looks to be a lot more expensive than fission reactors—which aren't cheap. Cost is a complicated problem.

Drollette: But the takeaway is fusion will be even more expensive than fission? By how much—10 times more?

Rosner: I really can't estimate that. But the fundamental reason is that the systems involved in fusion are even more complicated than in fission reactors.

Drollette: In your e-mail earlier about the difficulties facing fusion, you wrote about the supply of tritium—one of the fuels for a fusion plant—being a problem, at least in the short-term.

Rosner: The tritium supply is definitely an issue. Because tritium, unfortunately, has a relatively short lifetime. It can come about in nature as a byproduct of cosmic rays hitting the atmosphere. But it's not like there's a supply of tritium sitting in the ground, waiting to be excavated; there is no tritium mine. You have to make it. This is not true of the other fuel needed, namely deuterium, which is stable and is commonly extracted from water; “heavy water”—D₂O—can be found in ordinary water at concentrations of 15 parts per thousand.

And making tritium is itself a bit of a challenge. There are a number of ways of doing it: The ITER camp like to think they can make tritium as a side effect of running a fusion plant, by basically bombarding a layer of lithium-6 with neutrons.

Drollette: But you've got to have a fusion plant up and working before you can make the tritium.

Rosner: Again, easy to say; difficult to do.

That's part of the technical complexity of a fusion plant based on burning tritium and deuterium.

Drollette: We discussed how people should think about ITER—it's more of a longer-term thing, a science experiment.

Rosner: A science and *engineering* experiment. Yes.

Drollette: My impression is that means that people should not look to fusion as the solution to our climate change problems. It's just not on that kind of time-frame?

Rosner: The timescale is way off. Climate change is a serious problem which needs to be addressed by "decarbonizing" our energy generation systems sooner rather than later—by 2050 at the absolute latest. And we're not going to have practical fusion energy in that kind of time frame. There's no way.

One other thing: After this article is published, you'll find people will be objecting to it, saying: "But we have a much better idea." And there are in fact many different, privately financed companies exploring fusion, going in a variety of totally different directions and approaches.

Some of them involve beam fusion—which, in a sense, involves just pushing protons (or other particles to be fused) together at very high speeds.

For example, a company originally called "Tri Alpha"⁵ has this interesting idea of producing fusion energy without the intervention of neutrons by fusing protons with boron. That's important—for one thing, it addresses embrittlement.

But all of them have the same problem—technically, what they are talking about is even more complicated than what ITER is trying to do. And, in Tri Alpha's case, the temperature they must reach is actually much higher than a tokamak to get fusion, because Tri Alpha is trying to fuse protons with much larger nuclei—higher up the periodic table.

Of course, for fusion to happen those particles have to be going faster, because the repulsive forces are larger. So they must deal with much higher temperatures—temperatures well above 100-million degrees. So you can see it's very challenging territory.

But the key to understanding why these companies even exist at all is that along the way to fusion, the devices that they create can be used for many other things that are very likely to have commercial utility: plasma etching, X-ray sources, neutron sources.

That's how they think they can stay in business—because they'll probably have lucrative applications along the route to their eventual stated goal.

Drollette: That goes to my next question: Why are private firms so bullish on fusion? A *Nature* article that says that 65 percent of private companies predict a fusion plant will be delivering electricity by 2035.⁶

Rosner: (Laughs.) Well, yeah. But at least they're making something novel and useful along the way. Tri Alpha is a very good company to look at for that reason.

And there is a history of such things—that is, coming across a new and useful application while trying to make something else.

Fermilab, for example, helped build a proton accelerator for doing cancer therapy while working on proton colliders. So there are applications out there—and some of these companies are pretty clever in exploiting the opportunities presented by ostensibly researching fusion.

And of course, they're going to come to us and say, "Tokamaks and stellarators are old hat, we're in a totally different, much better regime." My response to that is: "Show me the timeline for how you get there, and how much it's going to cost to produce electricity."

My personal view is the people doing [these approaches] have an even greater challenge than the researchers that are working on tokamaks.

Drollette: So that explains an earlier e-mail, where you said that any reporter covering fusion was going to be "encountering a complex mixture of fact, half-truths and outright misinformation."

Rosner: Right. Demonstrate to me that I'm wrong.

Drollette: Any other comments?

Rosner: We haven't said anything about what many people seem to think is magnetic fusion's big competitor, inertial fusion—which is based on the premise that fusion energy can also be generated intermittently and without requiring plasma confinement. You do that by generating power that's produced by assembling a critical mass for ignition and then allowing it to burn for a very short time. The idea is that you get a short burst of energy, and then just plan on doing it over and over again. In that situation, there's no issue regarding plasma confinement.

Drollette: That's where NIF comes in?

Rosner: Yes. NIF was designed and built to generate fusion ignition events repeatedly, not steadily—and as an aside, Livermore's NIF project did not get a penny to study its use as an energy producer or reactor; that was almost an afterthought.

A colleague of mine—a first-rate physicist named Marvin Adams, a professor at Texas A&M, and now

at the Department of Energy—described how NIF has been used during the press conference that announced NIF’s first successful fusion ignition event on December 5, 2022: As part of his presentation to the press, he said that this event was a weapons shot, for the weapons program, full-stop. And he was right.

Now, it was an incredible success. But the reason it was a success is because it showed that the weapons program at Livermore was capable of delivering what they said it would deliver: a science-based program that used simulation codes to design and predict the performance of very complicated devices—like nuclear weapons.

And getting that laser-driven capsule to the point of fusion ignition, using Livermore’s simulation codes to design the actual fusion experiment, is actually comparable in complexity to modeling weapons.

It was not for demonstrating inertial fusion energy as a practical energy source. That is the takeaway.

The idea of actually building an inertial fusion reactor based on the NIF design is, in my view, an even much more audacious notion than building a practical reactor based on magnetic field confinement.

To make that happen, you’d need to have fundamental technical revolutions in so many areas, including laser systems capable of generating shots at a pace of 10 hertz (meaning 10 ignition events, or cycles, per second), energy extraction methods, and target fabrication rates of millions per day. Just mass-producing the capsule that exploded is a titanic challenge—as is the price. The fabrication cost of just that one test capsule was about \$100,000, and that you’d have to bring that down to tiny fractions of that cost.

Drollette: But whenever you see mentions of NIF, it’s always described as peaceful, nondestructive research into the fundamental processes of the universe. It’s never the weapons part.

Rosner: I don’t think anyone should be fooled by any public relations spin about why NIF exists. It exists because it has very practical applications important for our national defense—and both the Department of Energy and Livermore have been quite open about this.

But, lucky us, NIF also allows us scientists to address questions about fundamental processes of the universe, many of which are difficult—if not impossible—to answer in any other way. So, of course, I am happy that Livermore started its Open Science program to promote the basic science spinoffs from NIF.⁷ I like the idea of researchers being able to study the state of iron at pressures comparable to the center of the Earth. Or using it to examine the interiors of giant gaseous

planets—I mean, how cool is that? So I am incredibly happy that by building this NIF machine, that we can do this incredible science. That’s fine. But let’s be honest about how and why this thing came about.

Drollette: What about other countries? What’s happening with fusion research in China? I’ve reached out to a number of scientists for comment, working here and in China, with no luck so far.

Rosner: It’s very hard to know definitively. We do know the Chinese are investing in fusion on their own, even while partnering in ITER. Basically, the way I would put it is that the Chinese are not going to be left behind. They’re keeping up with everybody else.

On the laser end, it’s a different story. And this gets you into territory that’s highly classified.

What I’ve heard—and what I am about to tell you is *not* classified—I’ve heard rumors that the Chinese are building a machine with a delivered laser power that’s probably five times larger than what NIF is capable of.

For example, reaching 10 megajoules—instead of the 2 megajoules per laser system energy pulse that NIF is capable of—might well be an attractive target for them.

Certainly they are publishing in this domain.⁸

Drollette: Why is that important?

Rosner: At 2 megajoules of energy input to the target, NIF is operating on the edge of what you might call a cliff: Above that energy input, we think that ignition will really occur, and just below below that, ignition is very challenging to achieve. So there is an energy cliff at about 2 megajoules, below which ignition becomes unlikely.

The energy in the laser pulses that comes in from all 192 lasers at NIF goes into the compression of the capsule. It’s a super-complicated route because these laser pulses don’t really hit the capsule directly; there are inefficiencies all along the way.

But it turns out that at around 2 megajoules, the system is strong enough that all those inefficiencies are cast aside; enough power is delivered to compress the capsule, if the target is sufficiently spherical. You get a “burn”—a briefly sustained fusion event.

But that level is teetering on the edge—a little less than 2 megajoules and a burn won’t happen; a little more and it will happen a larger fraction of the time.

Right now, my understanding is that NIF has succeeded five times in getting a burn. Things don’t have to vary much in the capsule design and other experimental details to basically change the efficiencies, and you won’t get a burn.

At 10 megajoules, all those things become less relevant. It’ll burn every time; you’re now sufficiently far away from the cliff.

So, why are they [the Chinese government's researchers] doing this? I think it's not for energy research reasons. I think they're doing it because machines like this—and NIF is not the only machine out there—basically help you to design and build nuclear weapons without ever having to test them [in the open air or underground].

Indeed, you can find mention of this perspective in the open defense industry literature.⁹ This is not at all a secret but has been an openly acknowledged US goal since the Clinton administration in 1996 decided to support the Comprehensive Nuclear Test Ban Treaty and launched a program to assure the continued viability of the US nuclear stockpile without resorting to underground testing—the key step to launching what would become the “Science-based Stockpile Stewardship Program.”

At the end of the day, that's what NIF is all about: It's a key reason why we no longer carry out underground nuclear weapons tests. And this is the reason why I am a very strong supporter of NIF and other related experimental facilities: They do much to obviate the need to test such weapons. Their absence would be a real blow to nonproliferation efforts because the pressures to go back to testing nuclear weapons would be intense.

And if the Chinese reveal they have a 10-megajoule version of NIF, the pressure here in the United States is going to be just unstoppable to do the same; it *will* be built here as well. And what I'm guessing—and please understand, I don't have any insider information, this is just my uneducated view of this world—is that the Chinese may not want to advertise that they have it, precisely because they don't want to make us take that step.

Drollette: So China's deliberately downplaying its success?

Rosner: I can't say for sure. The information that's available on what they're doing in the inertial fusion domain is pretty sparse. So all we have is pure speculation. But there's clearly something going on.

Drollette: What's your takeaway from all we've discussed?

Rosner: Magnetic and inertial fusion is great fun, and fantastic science. While I think we will get to build magnetic confinement-based fusion power reactors (such as tokamaks) only in the distant future—meaning perhaps by 2100—I don't think this will ever be the case for inertial fusion (such as NIF's laser powered system). It will never be used as an energy source.

Of course, in physics, you can never really say the word “never,” right?

So it may be that in a millennium—the very distant future—maybe we'll figure out how to do it. But not in

my lifetime, for sure. And I think probably not in my children's lifetime, or my grandchildren's lifetime.

You might ask why would somebody who is a deep *Bulletin* supporter support NIF? The answer is simple: I really do not want us to go back to nuclear weapons testing. The fact is that we have a test ban that actually seems to work—except for North Korea—so it's been an incredibly powerful way of preventing more nuclear weapons proliferation.

It's the folks who don't have nice tools like NIF who need to do weapons tests [in real life instead of computer simulations]. So the existing ban on tests has really been pretty effective. And that's my motive for supporting inertial fusion work.

Notes

1. ITER is a giant, international research and engineering effort, based in France, which seeks to demonstrate how the basic power of the sun—fusion—could be reproduced here on Earth in the form of a magnetic fusion device. More details can be found at <https://www.iter.org/proj/inafewlines>.
2. Deuterium and tritium are two isotopes of the chemical element hydrogen. In other words, they have the same atomic numbers and positions in the periodic table as hydrogen, but different numbers of neutrons in their nuclei—which gives them different atomic masses and different physical properties.
3. NIF is an abbreviation for the National Ignition Facility, a laser-based device at Lawrence Livermore National Laboratory that is designed to study inertial confinement fusion; it does so by aiming 192 lasers at a small capsule containing hydrogen atoms. At the risk of oversimplifying, its goal is to create nuclear fusion in the laboratory by generating the same kinds of temperatures and pressures that exist in the cores of stars and giant planets—and inside nuclear weapons. More background information about its design and how it works can be found at <https://lasers.llnl.gov/about/how-nif-works>.
4. For more about ITER's management problems, see the *Bulletin* essay below that critiques ITER's organizational structure in light of scientific diplomacy and international politics. Written by Lucio Rossi, then-project leader of the Large Hadron Collider at CERN, it gives a thoughtful, reasoned look at ITER's problems, while pointing out that any large international “Big Science” project will inevitably encounter certain hiccups, which he outlines. See “ITER: The Giant Fusion Reactor—book review by plasma physicist who heads Large Hadron Collider,” in the July 30, 2020 free website of the *Bulletin of the Atomic Scientists*: <https://thebulletin.org/2020/07/iter-the-giant-fusion-reactor-book-review-by-plasma-physicist-who-heads-large-hadron-collider>. More on the concept of Big Science can be found at https://en.wikipedia.org/wiki/Big_science.

5. Founded in 1998 and now called TAE Technologies, this California-based, private company says that it aims to manufacture a prototype commercial fusion reactor by 2030. <https://tae.com/>.
6. See the July 8, 2024 *Nature* article titled “ITER delay: What it means for nuclear fusion.” The subheading says “The world’s biggest fusion-energy experiment is likely to be beaten to its goals by other projects—but the massive reactor still has value, say scientists.” <https://www.nature.com/articles/d41586-024-02247-2#:~:text=In%20a%202023%20survey%2C%2065,by%202040%2C%20he%20said.>
7. Now referred to as the “Discovery Science” program, it offers opportunities for a broad range of users to perform experiments at the National Ignition Facility in high-energy density science—including planetary science, high-pressure materials science, plasma physics, nuclear science, particle acceleration, and the branch of astronomy that focuses on understanding the physics of the universe, among other fields. <https://lasers.llnl.gov/science/discovery-science>.
8. See 2019 article “Experimental progress of inertial confinement fusion based at the ShenGuang-III laser facility in China,” by Shaoen Jiang, in *Nuclear Fusion* 59, 032006, available at <https://iopscience.iop.org/article/10.1088/1741-4326/aabdb6/meta>.
9. For more information, see the June 28, 2021 article “China’s Fusion Research Is Heating Up” by Thomas Corbett and Peter Singer, in *Defense One*. Available at <https://www.defenseone.com/ideas/2021/06/chinas-fusion-research-heating/174990/>.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributor

Dan Drollette Jr. is the executive editor of the *Bulletin of the Atomic Scientists*. For three years, he edited CERN’s on-line weekly magazine about computing and high-energy subparticle physics, in Geneva, Switzerland, where his office was 100 yards from the injection point of the Large Hadron Collider.