

RELIGIOUS DEBATE

State laws protecting religious freedom have sparked a national uproar and backlash from supporters of gay rights in recent weeks. Five views on the issue, from an ethics professor, a city councilman, two law professors and an advocate. **SD5**



SAN DIEGO NEWSMAKERS, IDEAS + OPINIONS

U-T

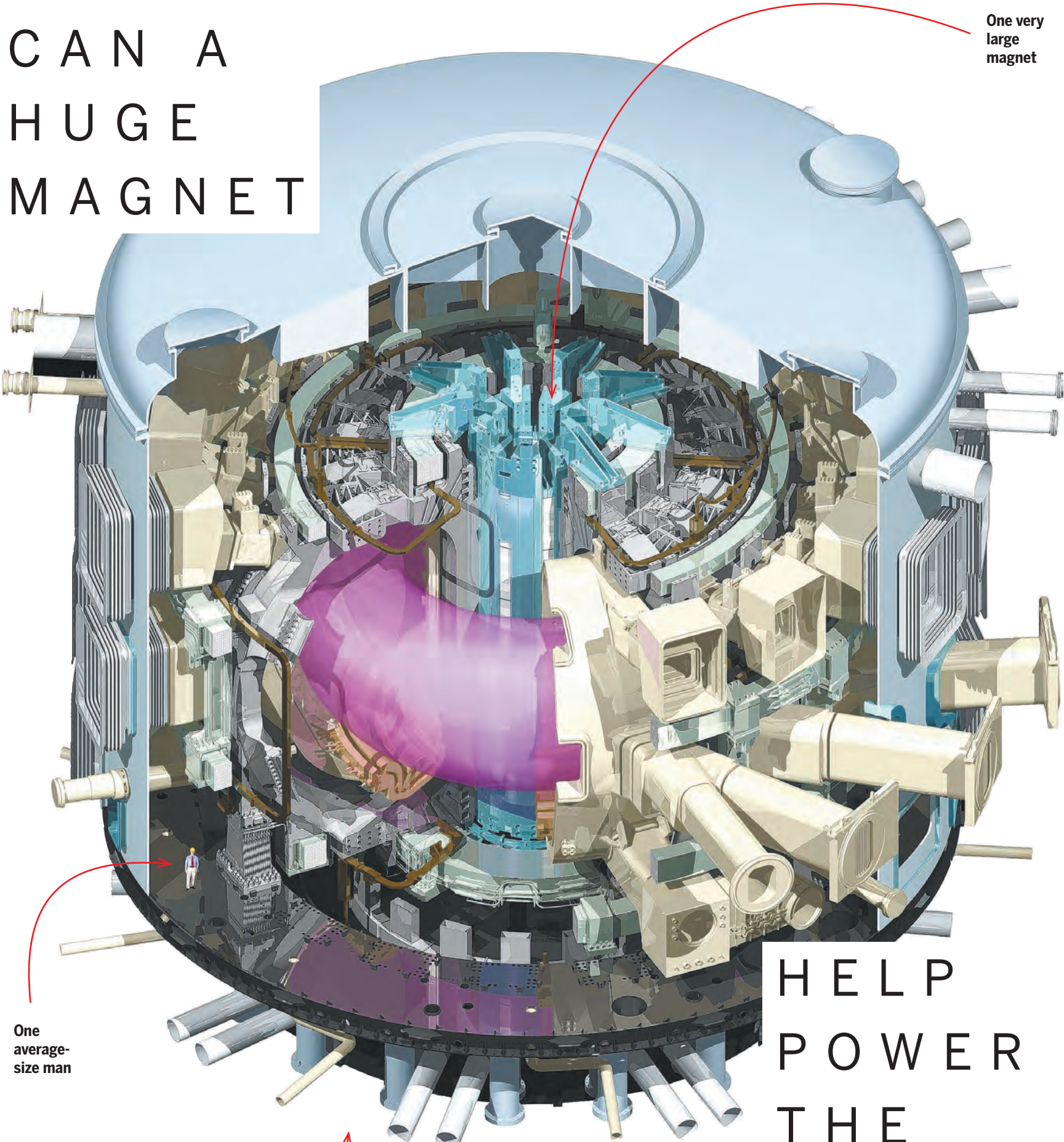
SUNDAY
APRIL 12, 2015

SECTION **SD**

SD IN DEPTH

SUN
DAY

CAN A HUGE MAGNET



One
average-
size man

One very
large
magnet

General Atomics of San Diego building device to be used for nuclear fusion experiments at reactor in France

GARY ROBBINS • U-T

San Diego's General Atomics is building a humongous magnet that will be used in an unprecedented attempt to prove that nuclear fusion — the process that powers stars — can produce almost limitless amounts of safe, affordable energy on Earth. The seven-story, 1,000-ton electromagnet will form the heart of a \$16 billion experimental fusion reactor that's under construction in southern France. It's the largest fusion feasibility study in history.

An international team of scientists will try to create and stabilize plasma, a distinct form of matter in which subatomic particles interact within electromagnetic fields. The researchers plan to generate this gas-like plasma by

SEE **MAGNET** • SD2



General Atomics technicians Bob Johnson (left) and Ryan Cartledge start the coiling process for the huge electromagnet that will be used in a fusion reactor in France. **HAYNE PALMOUR IV**
U-T

HELP POWER THE EARTH?

WINNERS & LOSERS

Your weekly news score card

WINNERS

Jenny Craig: A new study finds that the Carlsbad-based diet program is one of just two weight-loss plans medically proven to help people shed pounds and keep them off. Craig splits the dietary pie with Weight Watchers. Mmmm, pie.

► **UCSD:** Philanthropist Ernest Rady gives \$100 million to the university's Rady School of Management, which he helped establish more than 10 years ago. His gift, our gain.

Duke: A flock of freshman players lead the university to a win over



Wisconsin and the team's fifth NCAA title. No youth wasted here.

Batiquitos Lagoon: The Carlsbad ecological reserve gets more than 50 new acres and the herons and hikers get more room to move. Nature rocks!

Heroism: Gunnery Sgt. Brian Jacklin is awarded the Navy Cross at Camp Pendleton for leading his team through heavy fighting in Afghanistan to rescue two wounded comrades. They survived, we salute.

LOSERS

Rolling Stone: A Columbia University review determines that the magazine's disputed story about an alleged gang rape at

the University of Virginia was a journalistic disaster on every level.

TJ eats: Six eateries are shut down and five people are in custody after the discovery that a Chinese restaurant in Tijuana had been killing dogs and cooking their meat.

► Michael Thomas Slager:

The South Carolina police officer is charged with murder after a bystander's video shows him shooting Walter



Scott in the back as Scott was running away. Slager is white and Scott was black.

Privacy: It turns out the U.S. government started keeping records of our international phone calls almost a decade before the 9/11 terrorist attacks. Who knew? Oh, right. They did.

Water rules: Citing cuts and investments we have already made, San Diego's water agencies protest new state restrictions requiring cuts of up to 35 percent. It's going to be a long, hot haul.

KARLA PETERSON • U-T

Milestones in nuclear fusion

1929

Physicists Robert Atkinson and Fritz Houtermans predict that large amounts of energy could be released by fusing small atomic nuclei.

1939

Hans Bethe explains the fusion process in stars (which would later earn him a Nobel Prize).

1950

Soviet scientists Andrei Sakharov and Igor Tamm propose a fusion reactor.

1951

Argentina claims, falsely, to have created and controlled nuclear fusion, prompting massive U.S. research response.

1952

First hydrogen bomb is detonated by the United States at Eniwetok Atoll in the Pacific Ocean.

1953

Soviet Union successfully tests its first hydrogen bomb.

1957

John Lawson publishes now-famous criterion that establishes fact that any sustained fusion reaction requires a minimum number of fusion reactions per second.

1968

Soviets reveal results from the world's first controlled thermonuclear reactor, or Tokamak. Tokamak is a Russian acronym for toroidal magnetic chamber, referring to the doughnut-shaped device. The device contains high-temperature nuclear reactions with magnetic fields.

1973

U.S. Atomic Energy Commission negotiates a formal fusion exchange with the Soviet Union.

1976

Design work begins on the Joint European Torus, one of the largest experimental fusion reactors ever built.

1985

At the Geneva Summit, Soviet Union leader Mikhail Gorbachev proposes to President Ronald Reagan that an international project be established to develop fusion energy for peaceful purposes.

1986

General Atomics unveils the DIII-D Tokamak magnetic fusion research device in La Jolla.

1988

Conceptual design work begins for the International Thermonuclear Experimental Reactor, or ITER. The engineering design phase starts in 1992.

1989

Stanley Pons and Martin Fleishmann announce they have achieved “cold fusion” — fusion at room temperature. Their claims, which initially garnered much praise, are soon dismissed by other scientists as erroneous and premature.

1991

The JET Tokamak achieves the world's first controlled release of fusion power. San Diego is selected as headquarters for the \$1.4 billion international fusion-energy research project.

1994

Princeton University's Tokamak reactor produces 10.7 million watts of power from controlled fusion reaction, enough to power 2,000 to 3,000 homes temporarily.

2002

U.S. researchers publish a paper claiming to have detected fusion energy emitted from liquid bubbles exposed to sound waves. Like cold fusion, the “sonofusion” experiment is largely dismissed.

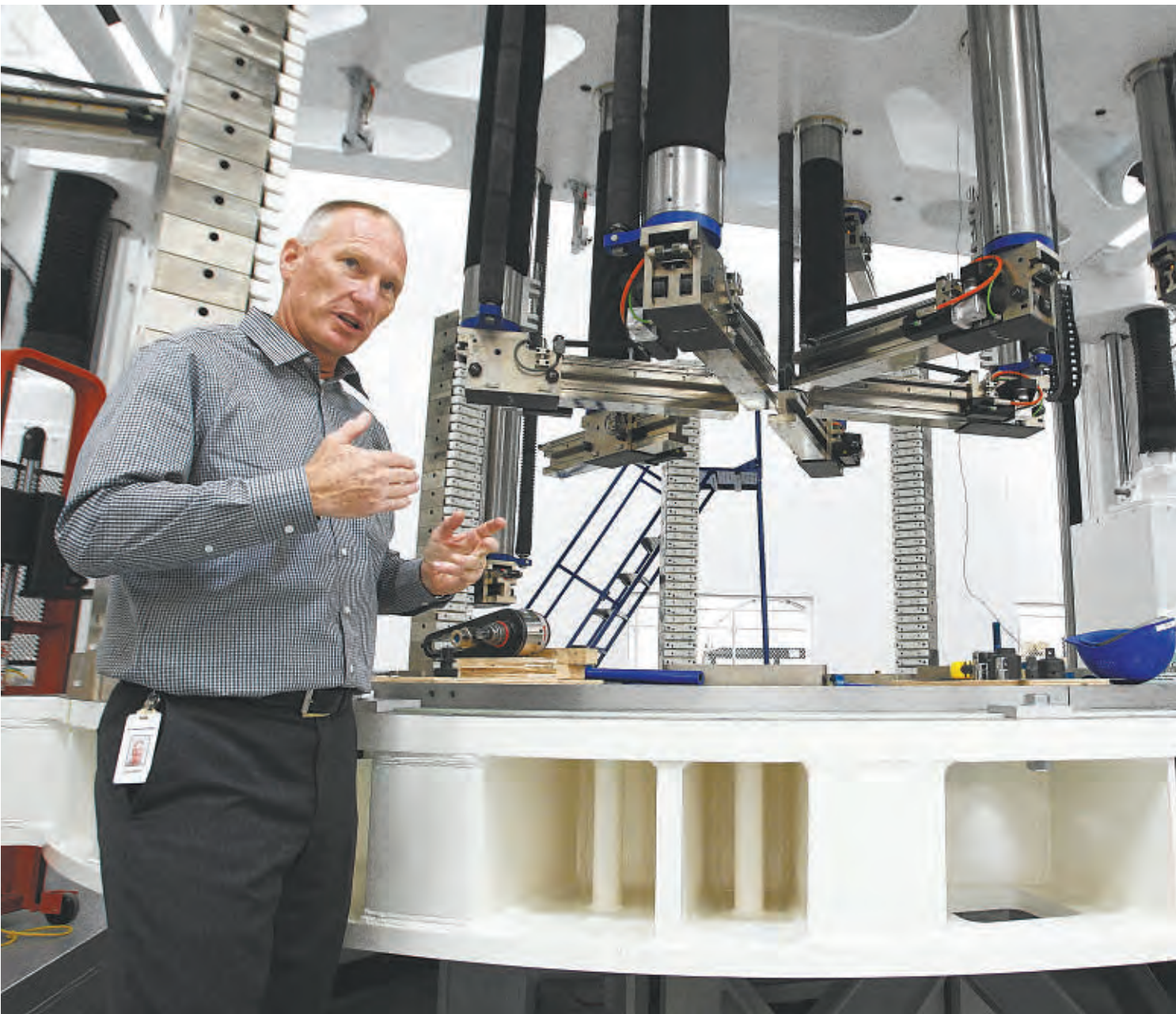
2005

Cadarache, France, is chosen as the site for the ITER project.

2015

General Atomics begins a process that will take a few years to complete — building a huge electromagnet that will form the core of the ITER fusion reactor.

Source: U-T research



John Smith, General Atomics' program manager for the ITER magnet, with the insulating machine in Poway. The 1,000-ton electromagnet will form the heart of a \$16 billion experimental fusion reactor under construction in France.

MAGNET

It's powerful enough to lift aircraft carrier, company says

FROM **SD1** heating hydrogen atoms to 10 times the temperature of the sun.

The magnet and two other complementary magnet systems are meant to control the plasma long enough for the atoms to fuse, leading to reactions that generate a net increase in energy.

Scientists have wrestled with the physics and engineering of commercial fusion for six decades, seeking alternatives to nuclear fission — think uranium in nuclear power plants — and carbon-based fuels, which are increasingly linked to climate change. The running joke is that fusion reactors will always be 30 years away.

“It's bloody complicated,” said George Tynan, a plasma physicist at UC San Diego who works on fusion.

General Atomics has hung in there.

The company operates a small, experimental reactor in La Jolla where scientists are investigating the basics of fusion. The company also runs a plant in Poway that's focused on how to manufacture the seven-story electromagnet for the International Thermonuclear Experimental Reactor, or ITER, which is being built in Saint-Paul-lès-Durance, France.

This month, it began putting together pieces of the magnet, which it said will be powerful enough to lift an aircraft carrier.

Various parts of this gigantic contraption will be trucked to Texas, then transported by sea to France, where ITER (pronounced “eater”) is tentatively scheduled to begin operating in 2020.

“It's exciting to work on a magnet whose end use could bring great benefit to the energy supply of the world,” said John Smith, General Atomics' program manager for the magnet. “At times, the task of building it seems daunting. But we're working to solve every challenge.”

There are great challenges to overcome — as well as great potential benefits.

Researchers have found that the energy released by fusing atoms together can be up to four times greater than fission, where atoms are split apart.

In addition, certain fusion methods are promising because they produce few radioactive particles. That would be a welcome contrast to a central byproduct of fission, in which spent uranium fuel from power plants must be kept indefinitely in highly secure facilities because of its radioactivity.

After decades of intense debate, the United States still hasn't been able to designate a central location where old



Conductor cable will be coiled at General Atomics in Poway to make a huge electromagnet for the ITER Tokamak in southern France. HAYNE PALMOUR IV • U-T PHOTOS

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John Smith • General Atomics program manager

uranium fuel rods and other nuclear waste can be stored. No community seems willing to have a nuclear dump as its neighbor.

There are also doubts among some policy makers and scientists about whether fusion represents an economical way of producing energy. Huge amounts of energy are needed to bring atoms, which naturally repel each other, close enough so nuclear forces can fuse them.

And fusion has comparatively few military applications, which limits how much money researchers can get from the federal government for their studies.

During the past decade, the Department of Energy has invested an average of \$375 million per year on fusion research. By comparison, the newer Navy destroyers in San Diego Bay cost about \$1.5 billion each.

With the ITER project itself, there have been concerns about the timetable and expense.

The undertaking was originally expected to cost \$5 billion. The United States agreed to pay about \$1.1 billion when it joined the effort in 2006. The rest of the money would be covered by partners from the European Union and other countries, including China.

Today, the project's overall cost has risen to \$16 billion, with at least \$4 billion of that coming from the United States.

Meanwhile, the construction and operation schedule has slipped by years.

The ITER reactor won't be finished until 2019, at the earliest. While partial operations are

slated for 2020, that date may slip further.

Years of basic physics testing will follow. In a review of the program, the U.S. Government Accountability Office said full-scale operations — when scientists will actually try to fuse deuterium and tritium — likely won't come until 2027.

Before that happens, scientists have to figure out a vexing problem: how to contain the superheated plasma inside the reactor.

“We've made progress in many areas, including getting the plasma temperatures we need (for fusion) in existing devices,” said William Heidbrink, a plasma physicist at UC Irvine. “But we've got to find ways to make sure the plasma won't damage the confinement wall.”

Scientists also have to figure out how to prevent the plasma from cooling off too quickly.

UC San Diego's Tynan said researchers need to slow “the cooling-off process so that this cool-down time is about a second or so. That is long enough to allow fusion reactions to occur and release enough heat to keep the plasma hot.”

Researchers have been struggling with such problems for decades, all the while adding fuel to the underlying question: Will fusion ever become a viable energy source for the world?

Tynan is circumspect: “We are pretty confident that we can use it to produce net energy. But the question ‘Will it be able to compete with other energy sources?’ is still open.”

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General Atomics history

1955

General Atomic is founded as a division of General Dynamics for research and development in the peaceful uses of atomic energy.

1956

Company convenes a conference of top nuclear experts in an Ocean Beach schoolhouse, which led to the design of the TRIGA nuclear reactor. The acronym stands for Training, Research, Isotopes, General Atomics.

1957

General Atomic and the Texas Atomic Energy Research Foundation begin a four-year, \$10 million research program in controlled fusion.

1958

TRIGA research reactor prototype is produced. Project Orion is proposed for development of a nuclear-powered interplanetary spacecraft.

1961

General Atomic introduces the Magneform metalworking machine, a byproduct of its research on controlled fusion.

1967

Gulf Oil acquires General Atomic.

1974

Royal Dutch/Shell becomes an equal partner in General Atomic with Gulf Oil.

1982

Gulf Oil buys Royal Dutch/Shell's holding in General Atomic, renames the company GA Technologies Inc.

1984

Chevron acquires GA Technologies along with Gulf Oil.

1986

GA Technologies unveils the DIII-D Tokamak magnetic fusion research device in La Jolla.

1988

Name is changed from GA Technologies to General Atomics.

1992

General Atomics Aeronautical Systems is formed.

1994

The unmanned aerial vehicle Predator makes its first test flight. General Atomics Aeronautical Systems is spun off.

2004

General Atomics wins contract to develop the Navy's first electromagnetic aircraft launcher.

2009

First demonstration of the Blitzler electromagnetic railgun, which General Atomics designed and manufactured.

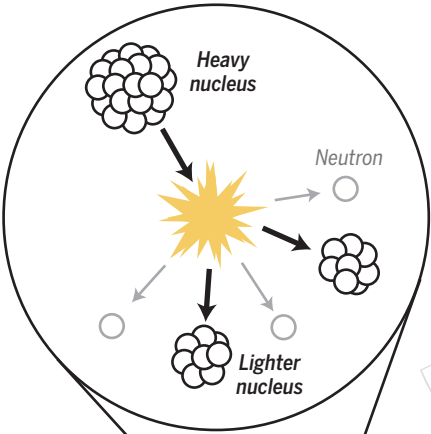
ENERGY'S HOLY GRAIL

San Diego-based General Atomics is contributing a super magnet to one of the largest science experiments ever one that may yield virtually limitless clean energy.

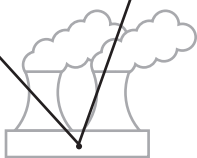
Old nuclear versus new nuclear

Nuclear fusion would be cleaner and more powerful than nuclear fission, which is what today's nuclear power plants use.

Nuclear fission occurs when an atomic nucleus breaks down into lighter nuclei. This process releases energy that can be converted into electricity.

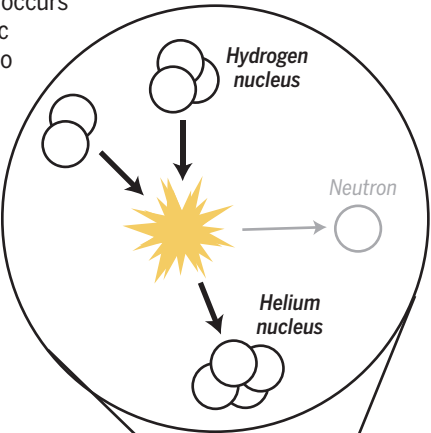


These lighter nuclei contribute to the nuclear waste that today's nuclear power plants must dispose of. Fission power also has the threat of a nuclear meltdown, such as what occurred in the Fukushima and Chernobyl cases.

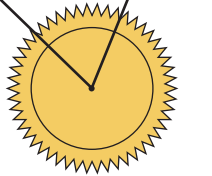


Nuclear fusion occurs when two atomic nuclei merge into one heavier nucleus.

This process also releases energy that can be used for electricity, but with little nuclear waste.

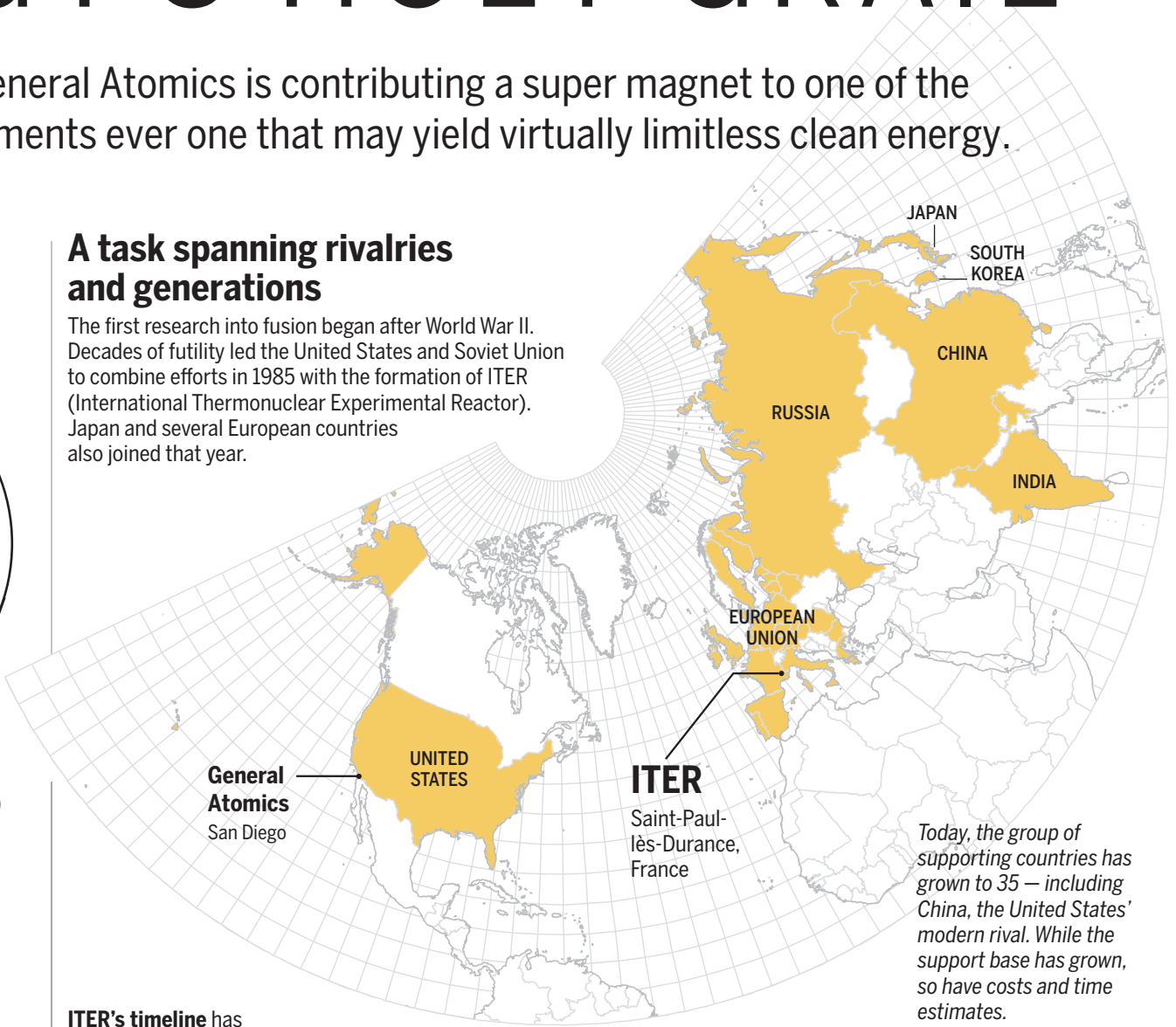


Fusion occurs constantly in the sun's core, where intense heat and gravity make it possible. Reproducing the right conditions on Earth to make fusion self-sustaining has been out of reach.



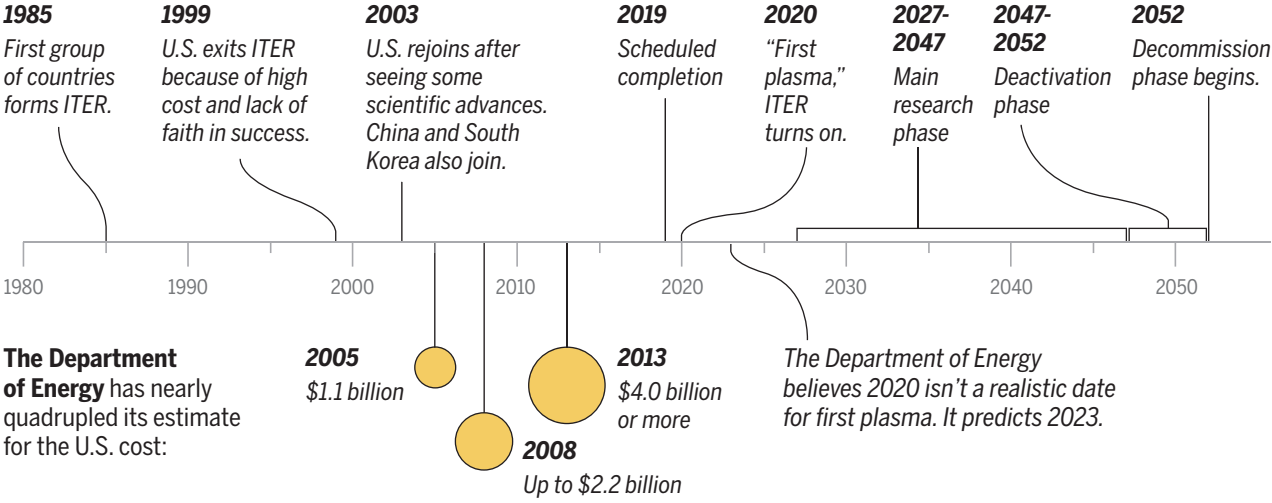
A task spanning rivalries and generations

The first research into fusion began after World War II. Decades of futility led the United States and Soviet Union to combine efforts in 1985 with the formation of ITER (International Thermonuclear Experimental Reactor). Japan and several European countries also joined that year.



Today, the group of supporting countries has grown to 35 — including China, the United States' modern rival. While the support base has grown, so have costs and time estimates.

ITER's timeline has the project reaching completion midcentury under ideal circumstances. A proposed demonstration power plant would send fusion power to the grid as soon as 2040.



Making a synthetic star

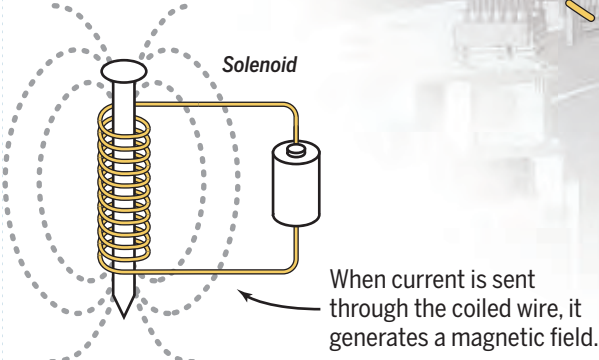
Fusion has been achieved in labs many times before, but always requires more energy to produce the reaction than the reaction puts out. While previous experiments have failed to "break even," ITER will attempt to leapfrog that goal and produce 10 times the power put in.

ITER can't duplicate the sun's gravity, so it will compensate with more heat. Its **plasma** will reach more than 270 million degrees Fahrenheit, 10 times hotter than the center of the sun.

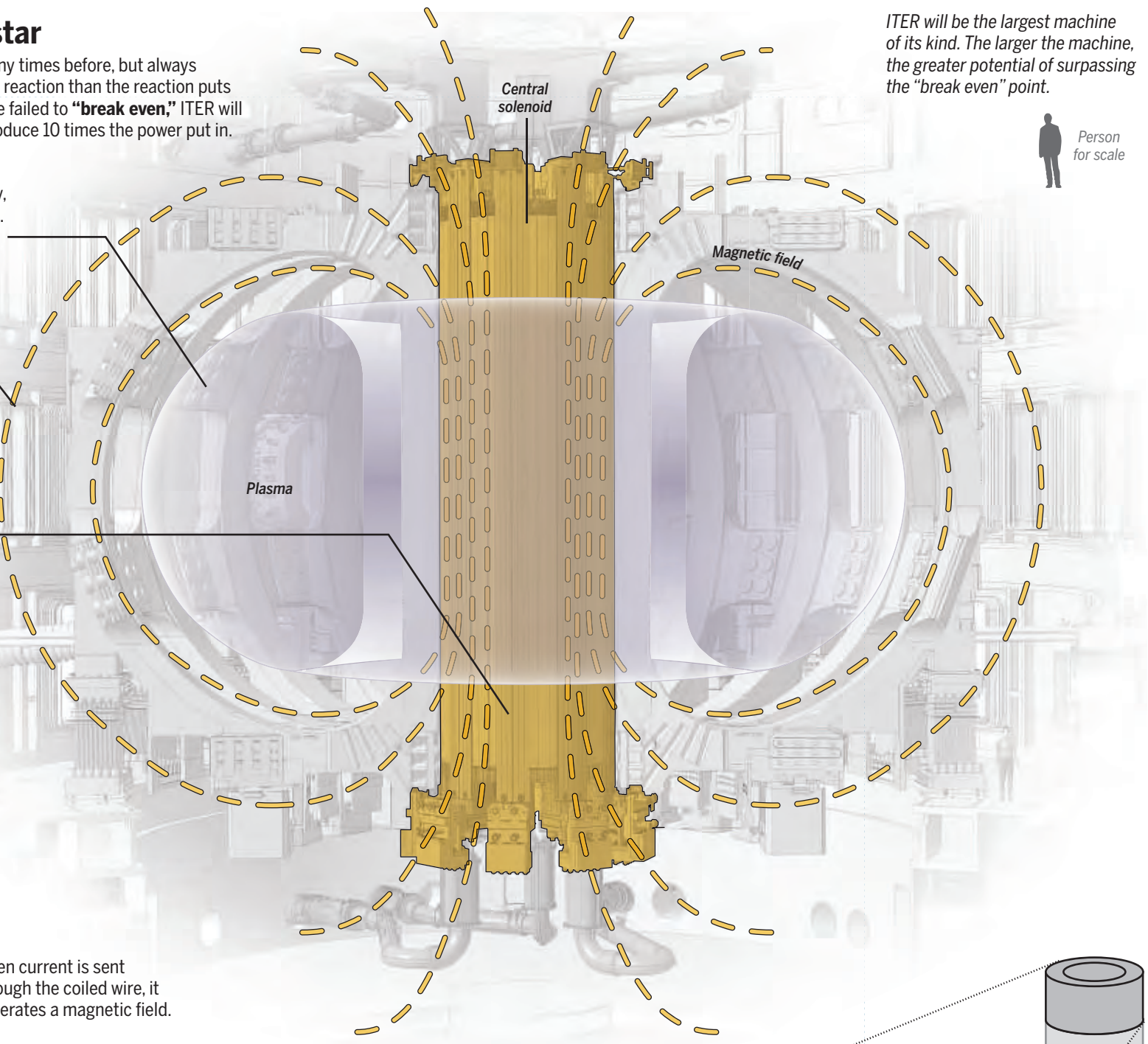
The plasma is far too hot for any material to contain, so it is held in a doughnut-shaped magnetic field.

The magnetic field will be created in part by the **central solenoid** — the component General Atomics is working on.

A solenoid is made in children's science experiments by wrapping a wire around a nail.



ITER will be the largest machine of its kind. The larger the machine, the greater potential of surpassing the "break even" point.

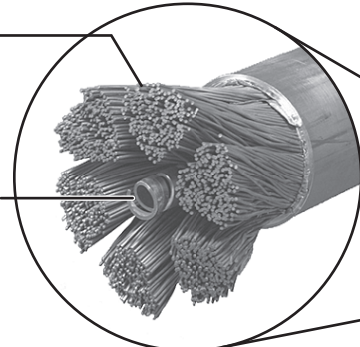


General Atomics coils the super magnet

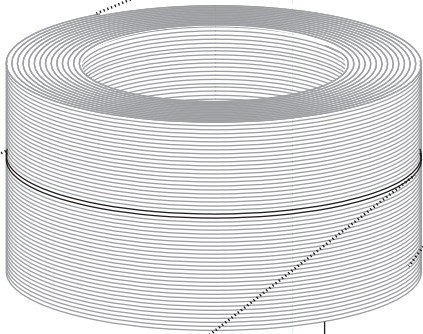
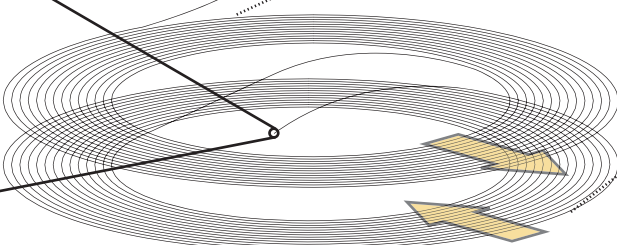
The conductor for the magnet was manufactured in Japan and delivered to General Atomics, where it is being coiled, heat treated, wrapped and coated before final shipment to France.

The cable is made of six smaller bundles, each containing dozens of strands.

A central tube runs liquid helium along the length of the cable to keep it cooled to near absolute zero.



The conductor is wound in an **inward spiral** for one layer and then on an **outward spiral** on the next one up.



Forty layers stack to make a single **subassembly**. They will make six subassemblies and one spare.

The subassemblies stack to form the **solenoid**. Together, they form a magnet that can produce twice the force of a space shuttle liftoff.