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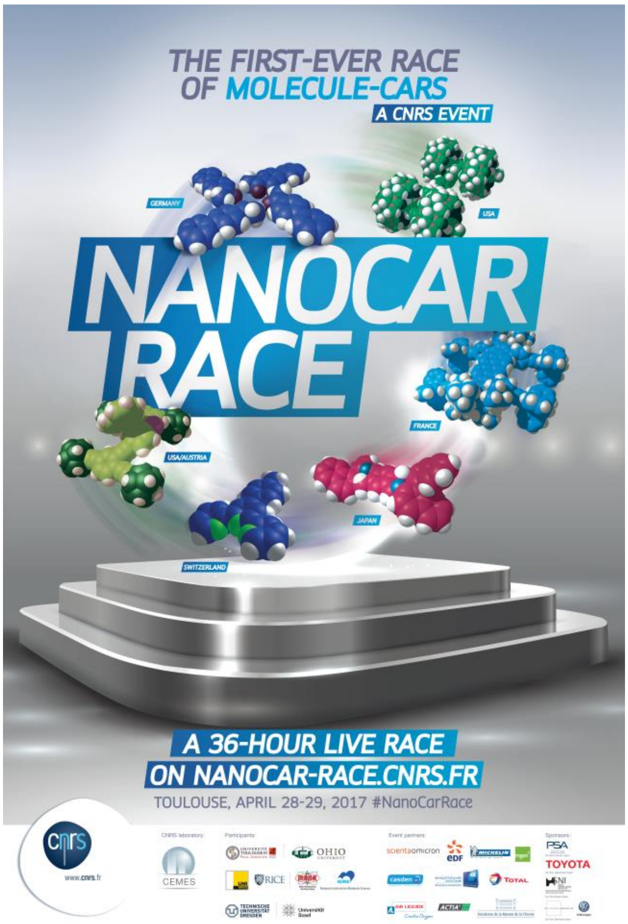
Nanocar Race: the first molecule-car race

The essentials of the race



A CNRS event

Contact
CNRS Press Officer I Alexiane Agullo I **T 01 44 96 43 90** I alexiane.agullo@cnrs-dir.fr

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The Nanocar Race is:

The Nanocar Race is a race in which machines, made up of only a few hundred atoms, compete on a gold racetrack 50,000 times thinner than a line drawn by a ballpoint pen. These nanocars, or molecule-cars, can have real wheels and a chassis, and move using energy from electric pulses.

This energy is provided by a specific instrument, known as a scanning tunneling microscope. Using a small electric current, the microscope's tip can visualize small objects, some up to 30,000 times smaller than a strand of hair. These electric pulses also enable the nanocars to move.

Microscopes of this type usually have only one tip. However, the CNRS's Centre d'élaboration de matériaux et d'études structurales (CEMES) in Toulouse has a unique instrument with four independently controlled tips—ideal for organizing a race and simultaneously driving four different molecule-cars!

Four teams, each with its own driving seat, will test four different molecular machines using the same microscope—and will do so at the same time and on the same surface. A world first!

A unique scientific experiment...

The Nanocar Race is the first opportunity for researchers to test, in real conditions, the simultaneous driving of several molecular machines designed independently of one another.

The Nanocar Race and associated development of nanocars promotes research in numerous domains. Beyond the competition itself, organizing the race and designing molecule-cars has led to significant scientific and technological progress, providing the physics and chemistry communities with answers to many unresolved questions in their fields.

Key notions:

Atoms and molecules:
Atoms are the fundamental constituents of matter. Each atom consists of a nucleus—made up of protons and neutrons—and electrons, which orbit this nucleus. Molecules are composed of atoms connected to one another through chemical bonds.

The researchers' objective here is to succeed in moving and steering a nanocar for 36 hours. More than speed, control over the trajectory is crucial, as well as being entirely novel. Months of testing were needed to design and drive a high-performance racing car. High command of molecular engineering is therefore essential to create the best possible machine.

The years to come will probably see the use of such molecular machinery to build common machines. It could also be of great use in the atom-by-atom deconstruction of industrial and urban waste, or the capture of energy, for example. The development of multi-tip instruments like the one at the CEMES-CNRS will also enable the synchronization of a large number of molecule-machines in order to increase their engine power, for storing or capturing energy from a hot metallic surface, for instance.

A one-of-a-kind microscope

The race will take place in a unique instrument, the LT-Nanoprobe, built by Scienta Omicron for the CEMES-CNRS, and financed by the Occitanie region in southwestern France, as well as the European Regional Development Fund (ERDF). The instrument consists of four scanning tunneling microscopes that can simultaneously and independently scan the same surface at low temperature and in an ultrahigh vacuum, providing images with a resolution of 2 picometers, or two billionths of a millimeter.

This type of microscope (called STM) uses the quantum mechanics phenomenon known as the "tunnel effect", which can very precisely measure the distance between an ultra fine metallic tip and a surface by using an electric current. The CEMES microscope is the only one in the world with four independent tips. Yet being able to visualize four sections of the racetrack is not its only achievement, as the microscope's four tips also provide the nanocars with the energy they need to move. Each of the four teams will have their own control screen for steering and controlling their car.

A gold racecourse

The gold surface was selected because most of the nanocars have few interactions with this surface, which must also be ultra-clean. The four courses will therefore have to be cleared simultaneously: as the race will take place at the nanometric scale (i.e. a billionth of a meter), the smallest speck of dust will be visible to the microscope, and could potentially disrupt the molecule-cars.

The entire gold surface will be prepared a first time, and simultaneously tested by each team. The molecule-cars will then be placed on this surface section by section. However, even with great care, molecules will be dispersed across the entire racetrack, and it is likely that some of them will end up in another competitor's section. Before the start of the race, each pilot will have to clean their dedicated zone by pushing "opposing" molecules one-by-one, and by clearing their own, in order to obtain a 70 to 100 nm molecule-free track.

The selected gold surface naturally shows highly regular folds in the shape of chevrons, with a gap of approximately 6 nm between them. Each competitor's track will thus be defined between 2 chevrons, consisting of 3 straight lines of 20 nm, 30 nm, and 20 nm, respectively, separated by a 45° right turn and a 45° left turn, for a total length of about 100 nm, based on the structure of the turns.

A race referee will be in charge of verifying that all of the tracks have the same atomic structure, as well as the same length between the start and finish lines. These two lines will be marked by the positioning of two molecule-cars that will not be used for the race.

Watch it live!

The enclosure in which the race will take place will be cooled to -269 °C, so that the molecules do not make any spontaneous movements, and are easy to manipulate. Liquid helium will be used for this cooling process, and the amount of the CEMES reserves limit the competition's duration to 36 hours.

For this first simultaneous driving test involving several molecular machines, the CNRS invites everyone to follow the different stages of the experiment livestream on the Nanocar Race’s You Tube channel.

A bilingual (French/English) presenter will bring the race to life for viewers thanks to a series of immersive cameras and a television studio installed in the laboratory. The detailed bilingual program will be posted on NanocarRace.cnrs.fr.

The public will therefore be able to follow the race live from the control room, with shots from the television studio, interviews, and summaries. This presentation will be interspersed with announcements of new events and videos of the teams, preparations, and partners.

The rules

For this first edition, all types of nanocars were accepted, even though it was recommended to use molecules with four wheels, a chassis, and an engine. The nanocars selected for the race have a chemical structure of at least one hundred atoms.

Since the mid-1990s, researchers have known how to manipulate a molecule at will by "pushing" it with the tip of the microscope. Today, the objective is to synthesize and control a particular form of propulsion using brief voltage pulses, called inelastic, without touching the molecule with the tip. The drivers must be particularly careful not to break the molecule's chemical bonds through too many pulses, or a succession of pulses too close together in time.

Each team will choose their own strategy for generating images. As it takes a minimum of approximately 3 minutes to obtain an image, they will have to decide whether to wait for several movements, or whether to record an image for each movement of the molecule.

Certain gold atoms could also move down the length of the scanning tunneling microscope's tip during these small electrical pulses, which would attract the nanocars onto the tip, and cause them to disappear from the scientists' control screen. The teams will be allowed to continue the competition by retrieving one of the cars evaporated on the surface at the beginning of the race, and set aside for this purpose (or to replace a broken nanocar).

However, if a team breaks its tungsten tip, it will be disqualified, as it is impossible to open the microscope to change tips.

The winning team will be the one whose molecule-car crosses its finish line first, or is the furthest along its track at the end of the 36 hours.

The organizers

Christian Joachim
Director of the race

CNRS senior researcher
christian.joachim@CEMES.fr

Jean-Pierre Launey
Race referee

Professor at the Université Toulouse III – Paul Sabatier
jean-pierre.launay@CEMES.fr

The CNRS's Centre d'élaboration de matériaux et d'études structurales (CEMES)

This laboratory, which was created in 1988, conducts basic research in materials science, solid-state physics, and molecular chemistry. It is associated with the Université Toulouse III - Paul Sabatier and the Institut national des sciences appliquées de Toulouse (INSA). Its activities primarily involve the production, study, and manipulation of nanomaterials. It also aims to develop cutting-edge microscopes and spectroscopes. The equipment and skills needed for picotechnology, i.e. technologies applied at a scale as small as a billionth of a millimeter, are housed within the PicoLab at the CEMES.

To find out more: PICOLAB, interacting with the nanoworld

The teams

US-Austrian NanoPrix Team

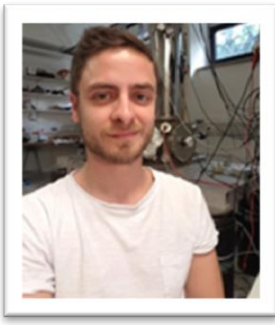
Name of the car: Dipolar Racer
Country: United States / Austria
Laboratories: Smalley Institute for Nanoscale Science and Technology (Rice University) / Institute für Chemie (University of Graz)
Team

Leonhard Grill
Team leader

Austria
Professor at the University of Graz
leonhard.grill@uni-graz.at

Victor Garcia-Lopez
Designer

United States
Associate Professor at Rice University
victor.garcia@rice.edu



Grant Simpson
Pilot

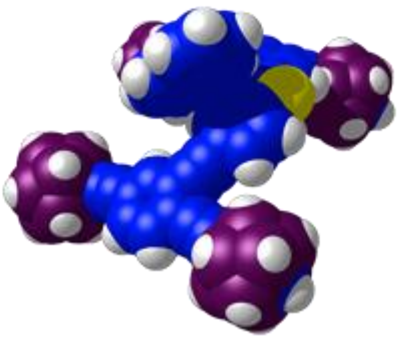
Austria
Associate Professor at the University of Graz
grant.simpson@uni-graz.at

James Tour
Team leader and designer

United States
Professor at Rice University
tour@rice.edu

Propulsion method:
The team has not yet chosen its final molecule for the race. A few are still undergoing optimization. Nevertheless, they adopted the same strategy as the other teams: the Dipolar Racer is propelled by the interaction of its dipole with the electric current supplied by the microscope.

Composition:
The Dipolar Racer is an assembly of different components: wheels, axles, chassis, and a motor that changes shape when exposed to a current.



Nano-windmill Company

Name of the car: Windmill
Country: Germany
Laboratory: Institute for Materials Science and Max Bergmann Center of Biomaterials - TU Dresden
Team:

Frank Eisenhut
Pilot

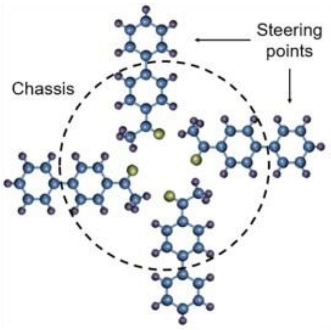
Germany
PhD student at Dresden University
frank.eisenhut@nano.tu-dresden.de

Francesca Moresco
Team leader and co-pilot

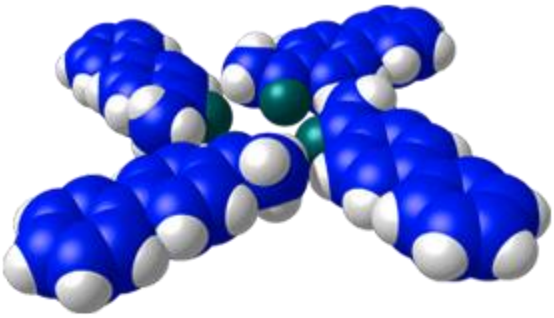
Germany
Senior researcher and lecturer at Dresden University
francesca.moresco@nano.tu-dresden.de

Propulsion method:
The electrical energy applied to the car is converted into motion. By using voltage electric pulses with the tip of the microscope, Windmill is able to move in a precise and controlled manner. The four molecules can be steered in one of the four possible directions.

Composition :
Windmill consists of four ABP (acetylbiphenyl) molecules connected by hydrogen bonds (the circle in the image). Electric pulses will be applied to precise steering points of the molecule .



ABP is commercially available, although the molecules must be assembled to form a nanocar. The conditions of evaporation of the molecule must be adjusted in order to maximize the formation of structures.



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NIMS-MANA team

Car name: NIMS-MANA car
Country: Japan
Laboratory: International Center for Materials Nanoarchitectonics
Team:

Katsuhiko Ariga

Japan
Senior researcher at NIMS-MANA
ARIGA.Katsuhiko@nims.go.jp

Marek Kolmer
Pilot

Poland
Researcher at Jagiellonian University
marek.kolmer@uj.edu.pl

Kosuke Minami
Chemist

Japan
Postdoctoral fellow at NIMS-MANA
MINAMI.Kosuke@nims.go.jp

Waka Nakanishi
Team leader and designer

Japan
Senior researcher at NIMS-MANA
NAKANISHI.Waka@nims.go.jp

Yasuhiro Shirai
Designer

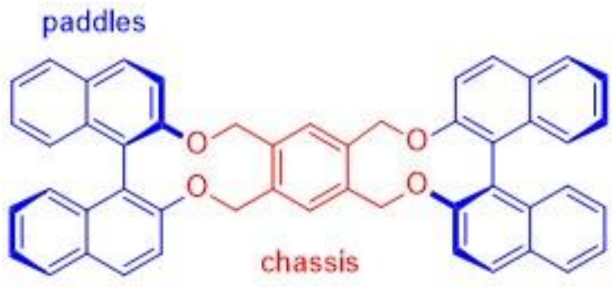
Japan
Senior researcher at NIMS-GREEN
SHIRAI.Yasuhiro@nims.go.jp

We-Hyo Soe
Pilot

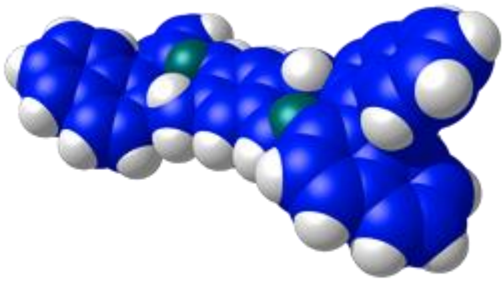
Japan
Researcher at NIMS-MANA
Toulouse Satellite
We-Hyo.Soe@cemes.fr

Propulsion method:
The molecules that make up the car can rotate around their bonds, moving in the manner of a caterpillar.

Composition :



The NIMS-MANA car is composed of two naphthalenes known for their odor. Each naphthalene acts as a kind of "paddle" for the NIMS-MANA car.



© NIMS-MANA

Ohio Bobcat Nano-wagon Team

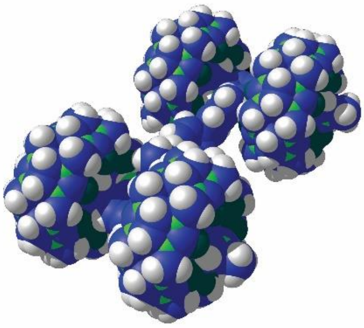
Car name: Ohio Bobcat Nano-wagon
Country: United States
Laboratory: Laboratory for single atom and molecule manipulation (Athens, United States)
Team:

Saw-Wai Hla
Pilot

United States
Professor at Ohio University
hla@ohio.edu

Eric Masson
Designer

United States
Professor at Ohio University
masson@ohio.edu



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To date, the team has preferred not to communicate on their car.

Swiss Team

Car name: Swiss Nano Dragster
Country: Switzerland
Laboratory: Nanolino Lab, University of Basel
Team:

Catherine Housecroft
Designer

Switzerland
Professor at the University of Basel
catherine.housecroft@unibas.ch

Tobias Meier
Co-pilot

Switzerland
PhD student at the University of Basel
tobias.meier@unibas.ch

Ernst Meyer
Team leader

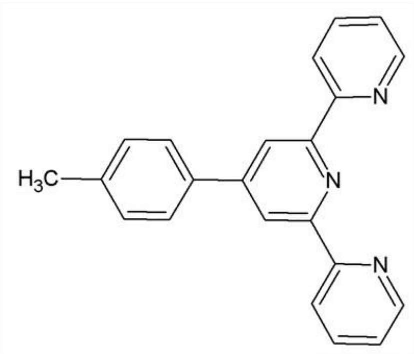
Switzerland
Professor at the University of Basel
ernst.meyer@unibas.ch

Rémy Pawlak
Pilot

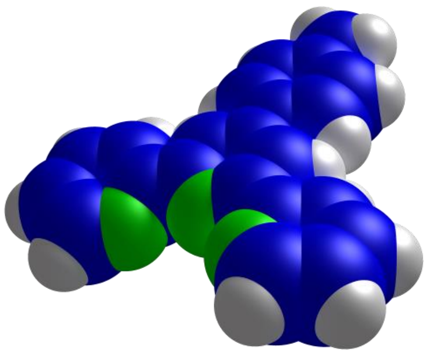
Switzerland
Postdoctoral fellow at the University of Basel
remy.pawlak@unibas.ch

Propulsion method:
The Swiss Nano Dragster is propelled by applying the microscope's electric pulses to its motor, which is located at the tail of the molecule (blue section in the image). The motor consists of three steering units. The Swiss Nano Dragster moves in different directions depending on the unit that is activated.

Composition :



The Swiss Nano Dragster does not have wheels, it is more like a hovercraft: the motion of the car is almost frictionless due to weak interactions between the molecule's (carbon-based) structure and the racetrack.



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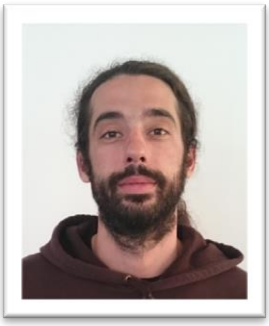
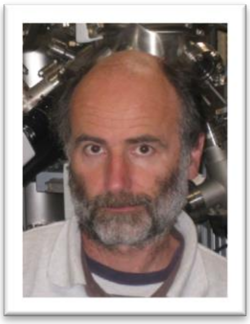
Toulouse Nanomobile club

Car name: The Green Buggy
Country: France
Laboratory: CEMES-CNRS/Université Toulouse III - Paul Sabatier (Toulouse, France)
Team:



Corentin Durand
Pilot

France
Associate Professor at the Université de Toulouse III – Paul Sabatier
corentin.durand@CEMES.fr



Sébastien Gauthier
Co-pilot

France
CNRS Senior researcher
gauthier@CEMES.fr

Claire Kammerer
Technical director

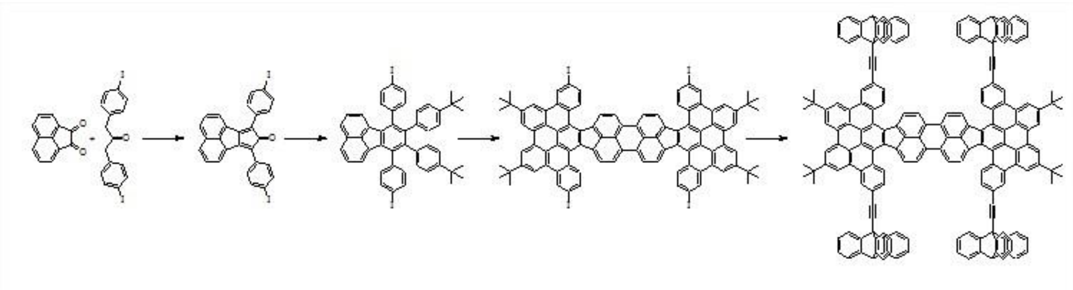
Associate Professor at the Université de Toulouse III – Paul Sabatier
claire.kammerer@CEMES.fr

Gwénaël Rapenne
Team leader and designer

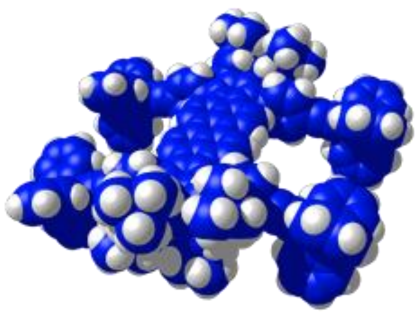
Professor at the Université de Toulouse III – Paul Sabatier
gwenael.rapenne@CEMES.fr

Propulsion method:
Each of the Green Buggy's wheels is equipped with a chemical group that can easily rotate around an axis, supplemented with a molecular ratchet. The tunneling current passing through this molecular group should trigger the rotation of a wheel and thereby propel the Green Buggy by 0.3 nanometers per electric pulse.

Composition :



As the construction of the nanocar proceeds, the size of the molecule increases (see image). The last step is the simultaneous connection of the four wheels using a coupling reaction.



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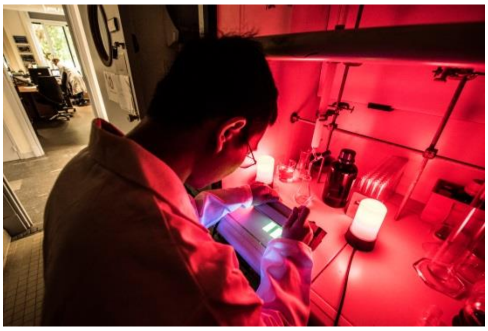
Resources

These and other visuals will be available at the CNRS photo library : http://phototheque.cnrs.fr/p/389-1-1-0/
For rush videos, please contact Alexiane Agullo: alexiane.agullo@cnrs-dir.fr

Designing the cars:



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The racetrack:

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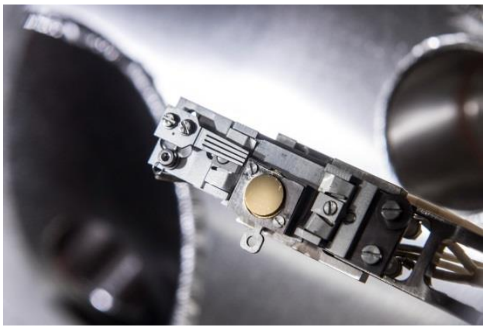

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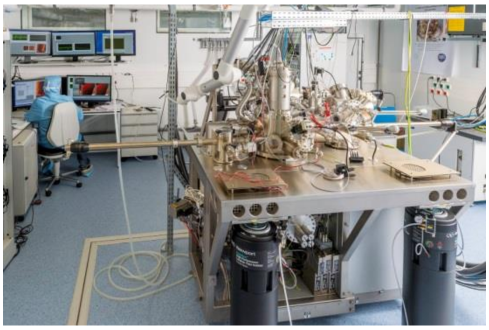
The microscope:



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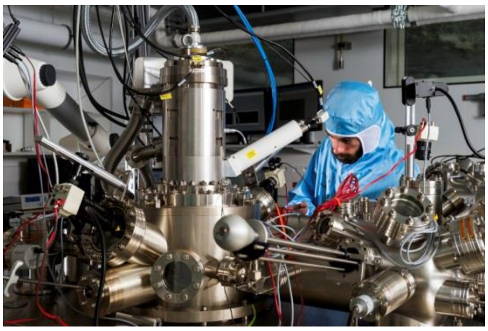

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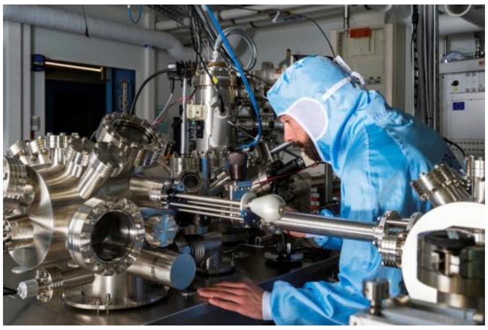

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