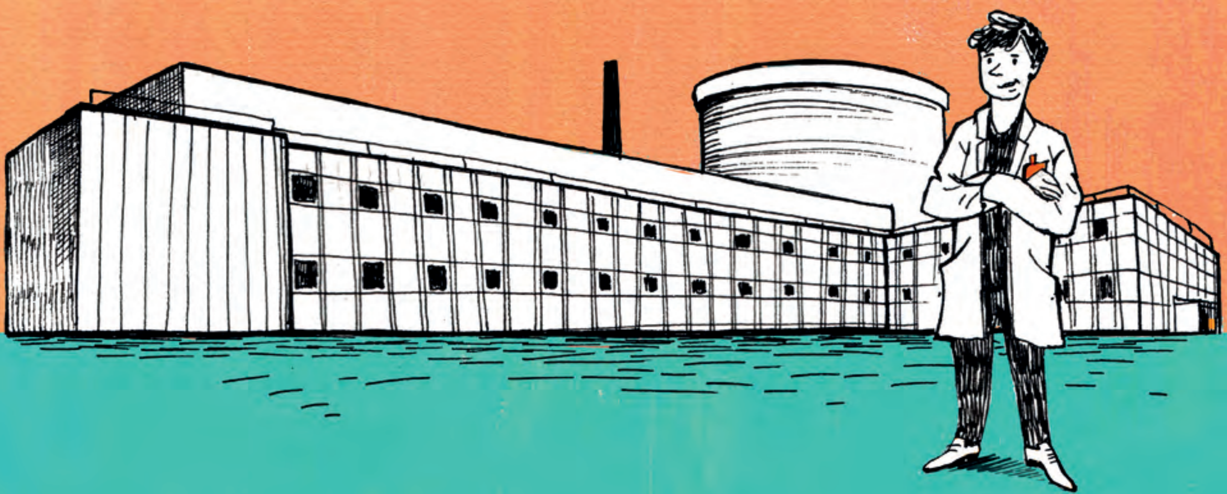
Let's scatter neutrons

ORPHÉE,

NUCLEAR RESEARCH REACTOR IN SACLAY



LÉON BRILLOUIN LABORATORY

Introduction

The Orphée neutron reactor, started in 1980 on the Plateau of Saclay, is due to close at the end of 2019. This will be the last research reactor built on French soil for scattering neutrons. Another type of neutron source is on the horizon, the ESS or "European Spallation Source" based in Sweden. Investigations are underway for a national compact source, SONATE.

The field of French neutron-based research (numbering 1500 users out of around 6000 for the whole of Europe) will therefore undergo profound changes in the years ahead. The French community will have to restructure itself, to call upon new talents and to envisage new modes of operation. The available beam time will drop sharply. One thing is certain; there will be no national source for the next decade.

Neutrons are an indispensable tool for studying matter, whether solid or liquid. They penetrate matter well, are sensitive to light atoms, "seeing ” their magnetism. Being waves and particles at the same time, they probe the distances between atoms and their movements. With the closure of the various European reactors, this tool will become scarce, until such time as the new sources become available.

For this reason we want to show you how Orphée functions, and to show the daily tasks of the researchers and technicians who have been working with the instrument for nearly 40 years. Orphée, a medium-power reactor, has been the scene of a few little miracles, allowing small teams, scientific or technical, to achieve major results. It has also provided training for thousands of students and visiting researchers.

For reasons of security, the general public have very little knowledge of the life of a TGI (= Very Large Instrument) researcher or a technician. Most residents of the Plateau of Saclay have no idea of what happens inside the reactor. Our job has its specific demands - the constraints, working in a limited timeframe, the strict selection of projects - amply compensated for by the joy of original discoveries or innovative achievements.

In this comic-book, we want to present the daily work of Orphée. Imagine visiting the Festival of Science, discovering the world of Orphée and chatting to some of its inhabitants. They speak a kind of foreign language, their own scientific jargon, which you have to translate into everyday language *.

Aurélie Bordenave, a graphic artist, took the challenge. She spent two days in the reactor (don't worry, we let her out in between!) She asked many questions, wrote down the answers, collected anecdotes, and shared our labor (and it's heavy, the door of an airlock). She gave us her vision, which is what we're offering you today. Aurélie's super drawings will tell you much more than mere words.

This vision, which is of course biased, patchy and subjective, doesn't claim to exhaust the richness of the Orphée story, which remains an exceptional human and scientific adventure. Historians or journalists may write the full story one day, but in the meantime, we hope we can make you feel the richness and beauty of this craft. And who knows, maybe it will ignite your ambitions?

Alain Menelle
Deputy Director
Léon Brillouin Laboratory

Isabelle Mirebeau
Director of Research at CNRS
Physicist, Léon Brillouin Laboratory

* If you are still puzzled by the language, there's a helpful glossary on the back cover!

Reactors and Spallation Sources

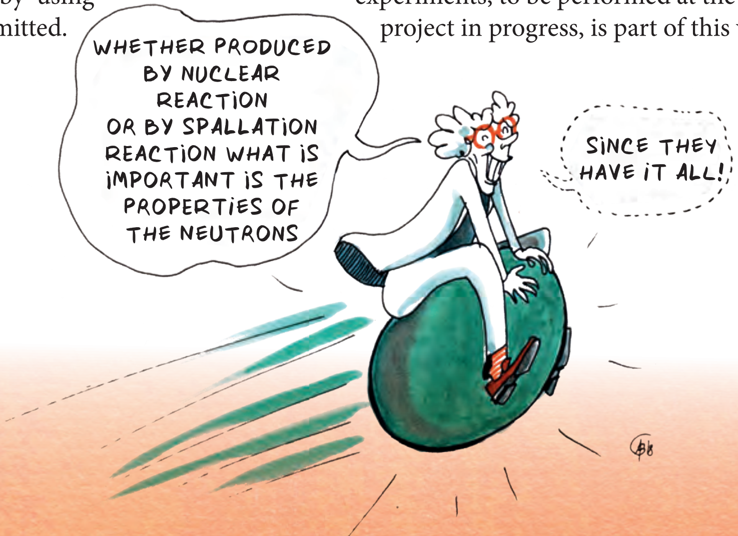
Originally, neutron scattering experiments were mostly carried out in large nuclear-reactor-based facilities. These reactors provide a continuous neutron beam from the fission chain reaction of uranium atoms. Neutrons of all energies are produced continuously, which must then be selected for the needs of the experiment. Therefore, only a very small percentage of the neutrons produced are actually used.

In recent years, the closure of these installations has begun. The closure of Orphée in 2019 follows that of the Julich and Geesthacht reactors in Germany. It will coincide with the Berlin reactor shutdown, while the future of the Institut Laue Langevin in Grenoble, one of the world's most powerful research reactors and one of the oldest, is not guaranteed beyond 2028. In the long term, most reactors in Europe, with the exception of the Munich reactor, will stop.

Other, more expensive facilities now take over: the spallation sources*. In such a source, the production of neutrons is not based on a nuclear fission reaction as in a reactor, but on the spallation reaction. A linear accelerator generates pulses of protons which bombard a target, pulling neutrons out of it by successive collisions. The neutron beam is therefore pulsed to work more efficiently by using most of the neutrons emitted. The time interval between the pulses makes it possible to separate the different energies by the time of flight technique *. This involves different working methods and data processing, requiring major developments on the part of the scientific community. The substantial gains promised by these new sources open up new scientific perspectives.

At present there are few spallation sources. The most important ones are located in England, the United States and Japan. Europe is currently developing the world's most powerful source, ESS (European Spallation Source), under construction in Lund, Sweden. The ESS uses a proton beam about 88% the speed of light, to bombard a tungsten target and produce neutrons. It won't become operational until 2023 and at will be at optimal performance by 2030.

How to prepare for such a change? Building a network of national sources seems like a good strategy. These sources, based on a principle similar to spallation, but of lesser flux and built at a more modest cost, can't compete with high flux sources. However, they will make it possible to carry out numerous experiments, to train future researchers and students, and to ensure a good preparation of more ambitious experiments, to be performed at the ESS. SONATE, a project in progress, is part of this vision.



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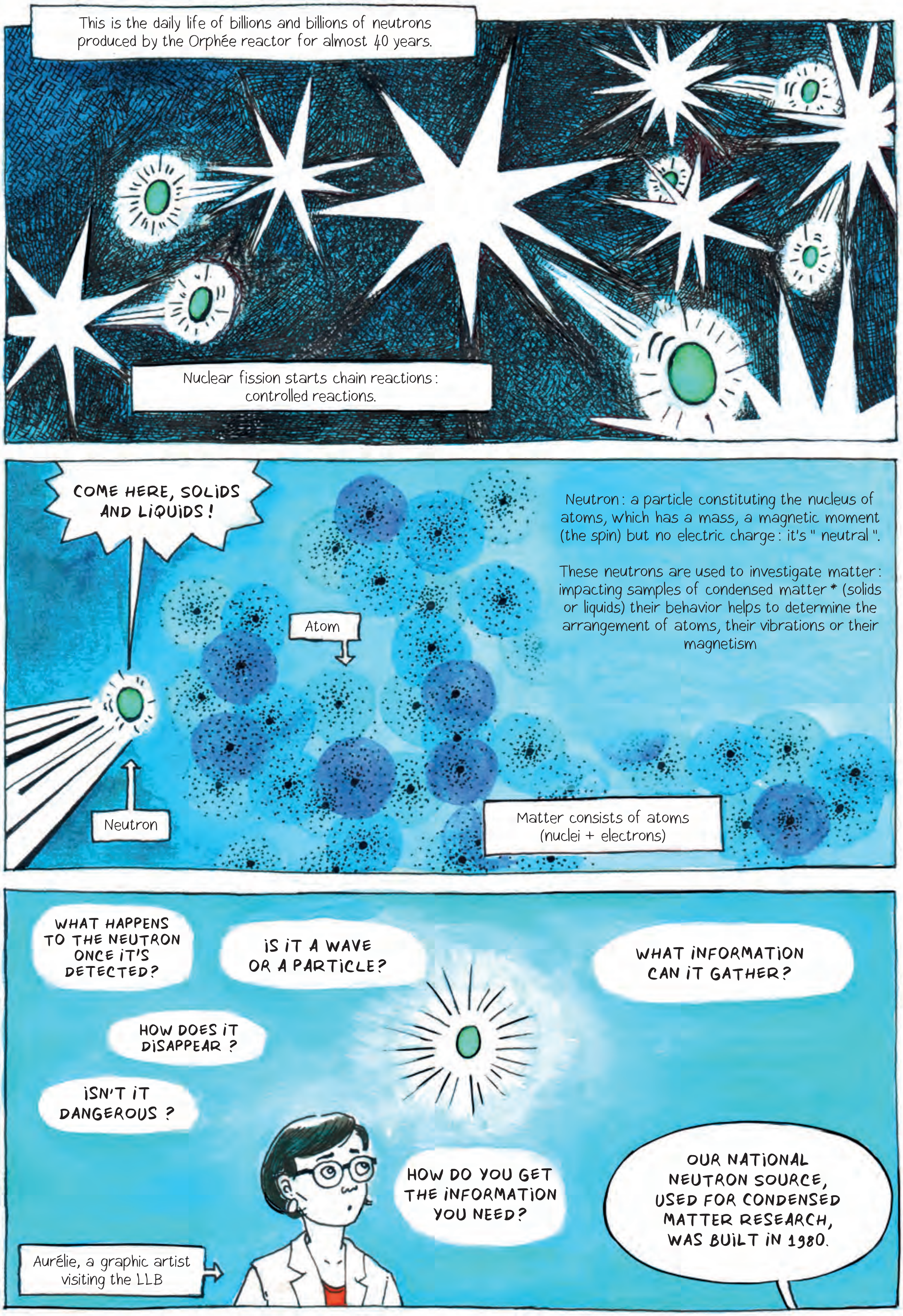
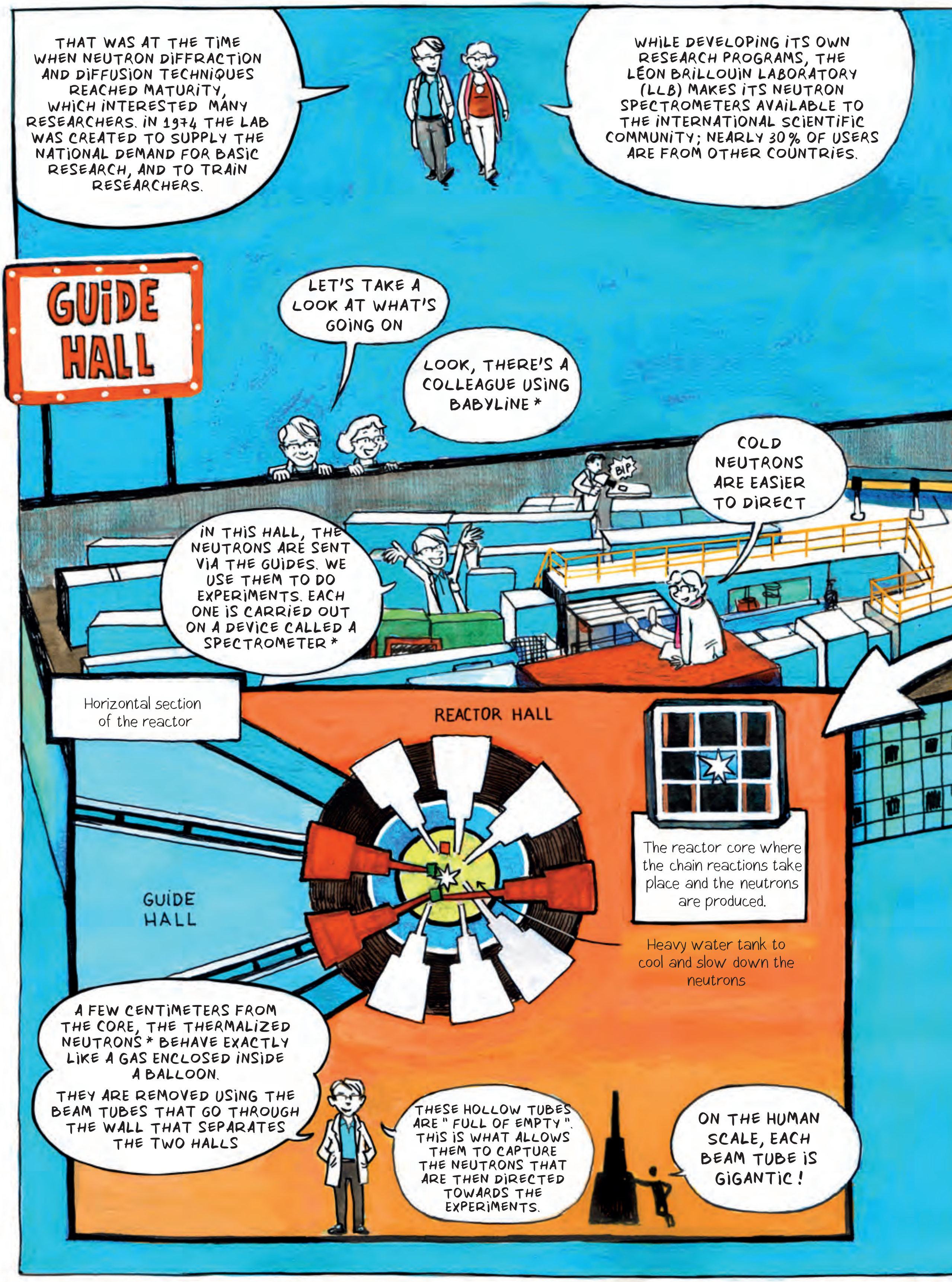
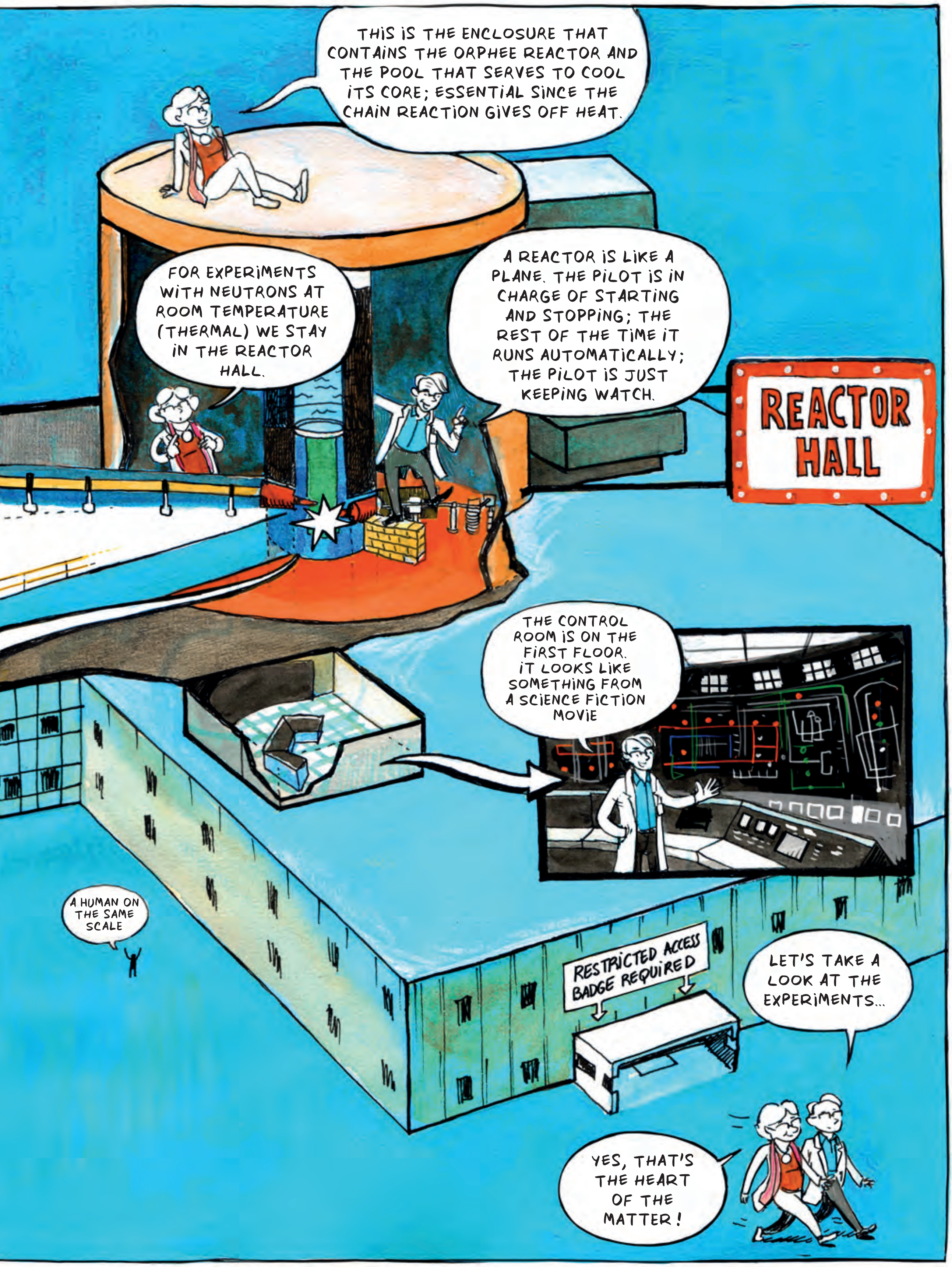
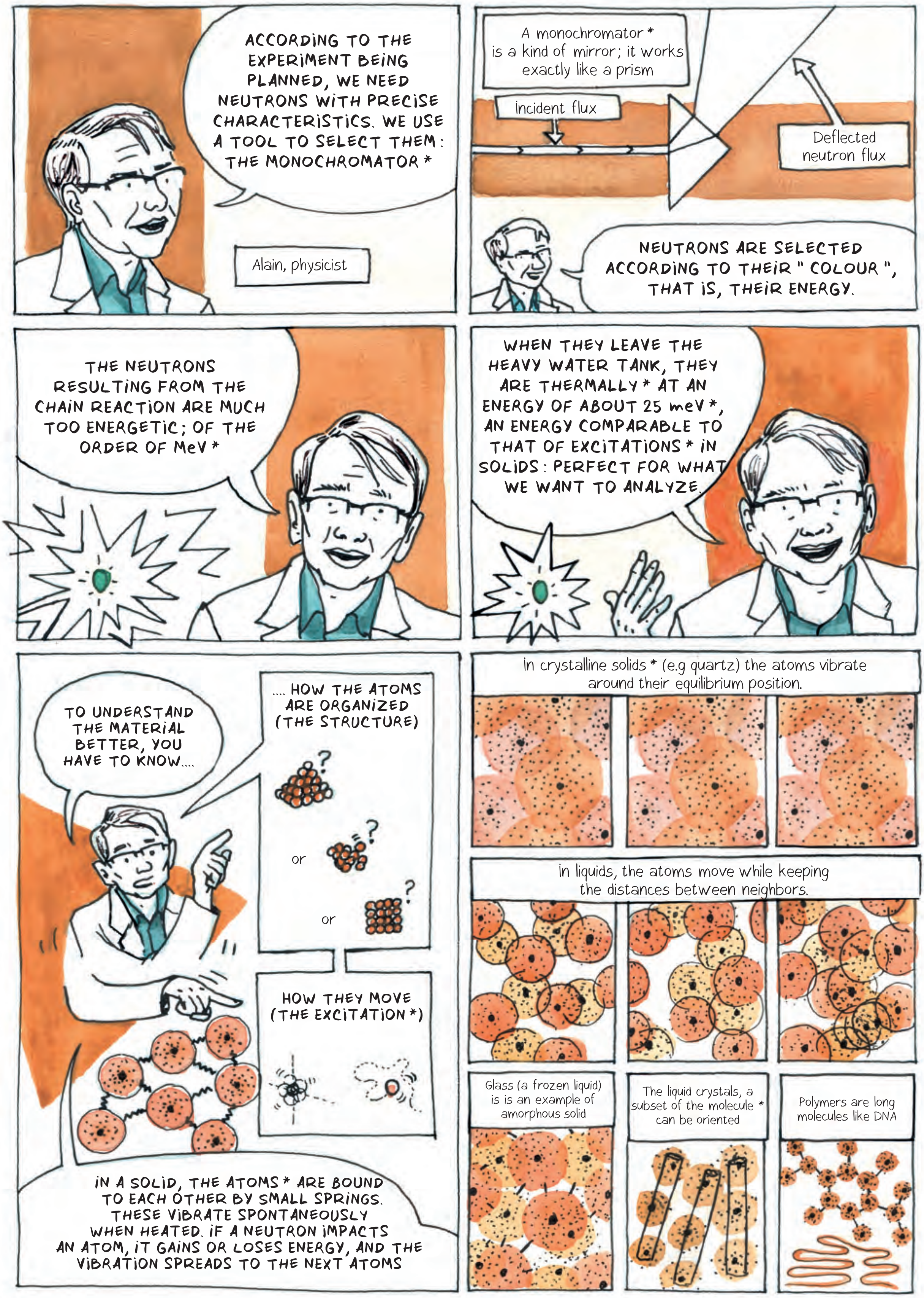


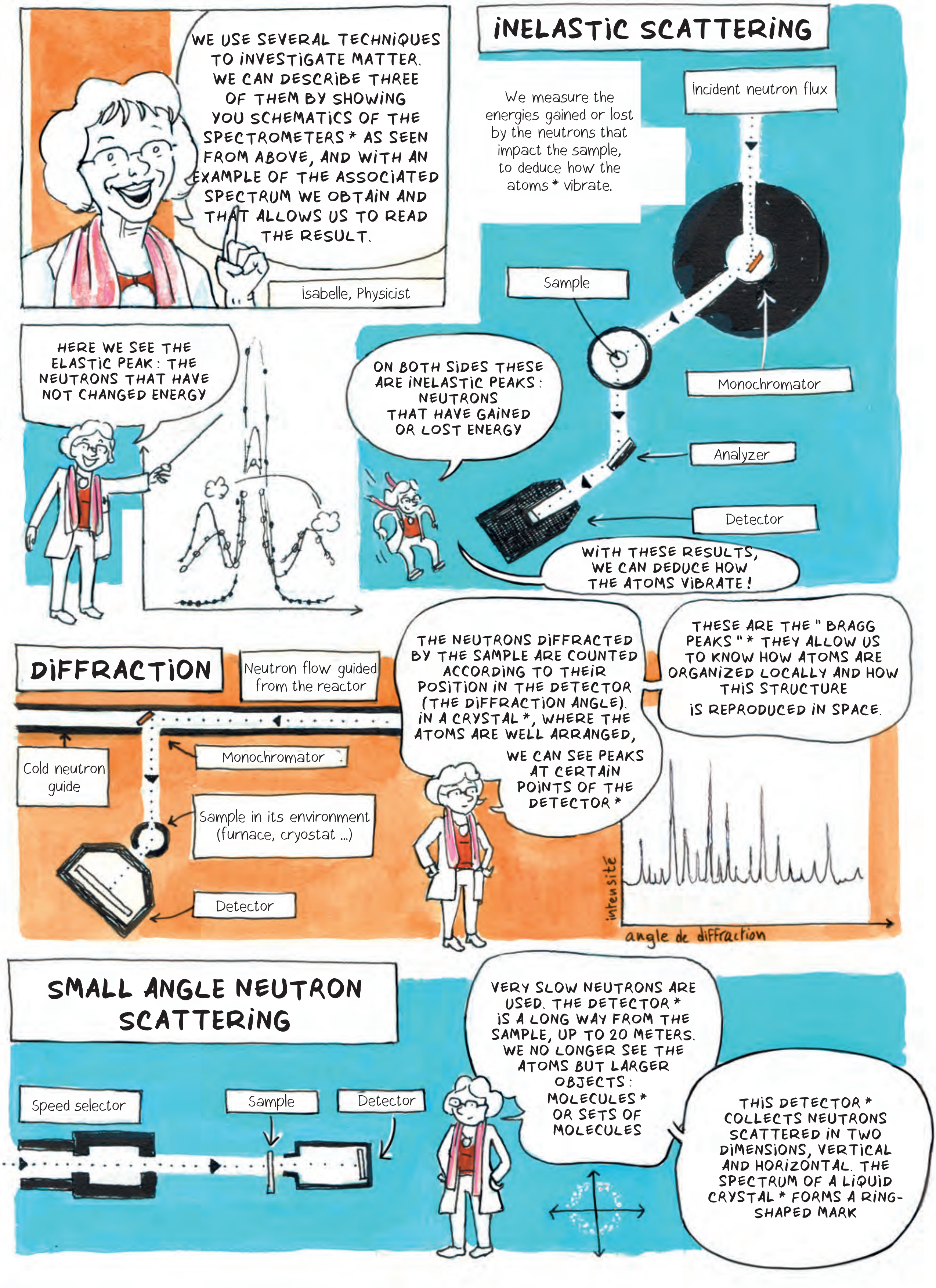
This is the daily life of billions and billions of neutrons produced by the Orphée reactor for almost 40 years.
Nuclear fission starts chain reactions: controlled reactions.
COME HERE, SOLIDS AND LIQUIDS!
Atom
Neutron
Neutron: a particle constituting the nucleus of atoms, which has a mass, a magnetic moment (the spin) but no electric charge: it's " neutral ".
These neutrons are used to investigate matter: impacting samples of condensed matter * (solids or liquids) their behavior helps to determine the arrangement of atoms, their vibrations or their magnetism
Matter consists of atoms (nuclei + electrons)
WHAT HAPPENS TO THE NEUTRON ONCE IT'S DETECTED?
IS IT A WAVE OR A PARTICLE?
WHAT INFORMATION CAN IT GATHER?
HOW DOES IT DISAPPEAR ?
ISN'T IT DANGEROUS ?
HOW DO YOU GET THE INFORMATION YOU NEED?
OUR NATIONAL NEUTRON SOURCE, USED FOR CONDENSED MATTER RESEARCH, WAS BUILT IN 1980.
Aurélie, a graphic artist visiting the LLB


THAT WAS AT THE TIME WHEN NEUTRON DIFFRACTION AND DIFFUSION TECHNIQUES REACHED MATURITY, WHICH INTERESTED MANY RESEARCHERS. IN 1974 THE LAB WAS CREATED TO SUPPLY THE NATIONAL DEMAND FOR BASIC RESEARCH, AND TO TRAIN RESEARCHERS.
WHILE DEVELOPING ITS OWN RESEARCH PROGRAMS, THE LÉON BRILLOUIN LABORATORY (LLB) MAKES ITS NEUTRON SPECTROMETERS AVAILABLE TO THE INTERNATIONAL SCIENTIFIC COMMUNITY; NEARLY 30 % OF USERS ARE FROM OTHER COUNTRIES.
GUIDE HALL
LET'S TAKE A LOOK AT WHAT'S GOING ON
LOOK, THERE'S A COLLEAGUE USING BABYLINE *
BIP
COLD NEUTRONS ARE EASIER TO DIRECT
IN THIS HALL, THE NEUTRONS ARE SENT VIA THE GUIDES. WE USE THEM TO DO EXPERIMENTS. EACH ONE IS CARRIED OUT ON A DEVICE CALLED A SPECTROMETER *
Horizontal section of the reactor
REACTOR HALL
GUIDE HALL
The reactor core where the chain reactions take place and the neutrons are produced.
Heavy water tank to cool and slow down the neutrons
A FEW CENTIMETERS FROM THE CORE, THE THERMALIZED NEUTRONS * BEHAVE EXACTLY LIKE A GAS ENCLOSED INSIDE A BALLOON.
THEY ARE REMOVED USING THE BEAM TUBES THAT GO THROUGH THE WALL THAT SEPARATES THE TWO HALLS
THESE HOLLOW TUBES ARE " FULL OF EMPTY ". THIS IS WHAT ALLOWS THEM TO CAPTURE THE NEUTRONS THAT ARE THEN DIRECTED TOWARDS THE EXPERIMENTS.
ON THE HUMAN SCALE, EACH BEAM TUBE IS GIGANTIC !

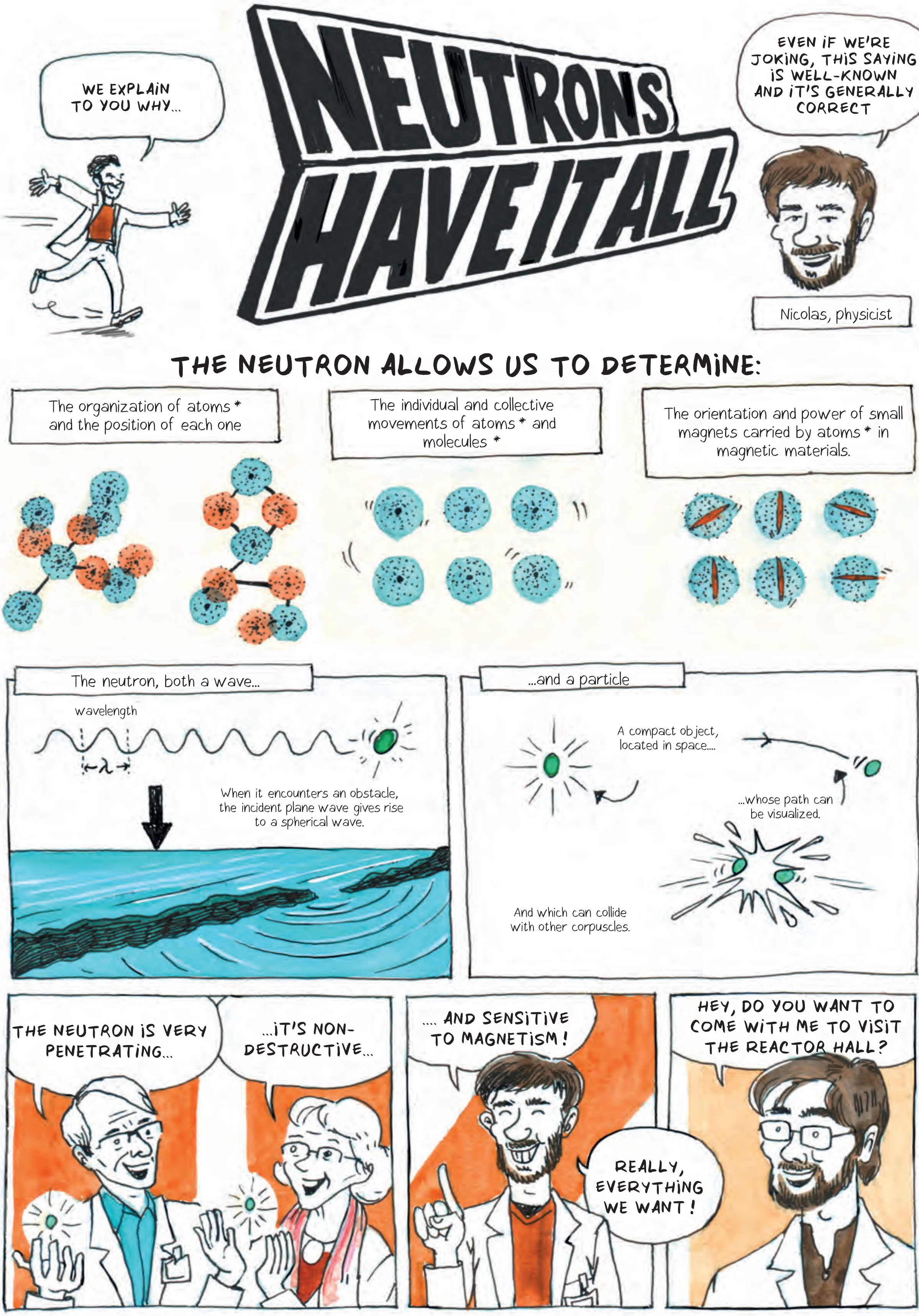

THIS IS THE ENCLOSURE THAT CONTAINS THE ORPHEE REACTOR AND THE POOL THAT SERVES TO COOL ITS CORE; ESSENTIAL SINCE THE CHAIN REACTION GIVES OFF HEAT.
FOR EXPERIMENTS WITH NEUTRONS AT ROOM TEMPERATURE (THERMAL) WE STAY IN THE REACTOR HALL.
A REACTOR IS LIKE A PLANE. THE PILOT IS IN CHARGE OF STARTING AND STOPPING; THE REST OF THE TIME IT RUNS AUTOMATICALLY; THE PILOT IS JUST KEEPING WATCH.
REACTOR HALL
THE CONTROL ROOM IS ON THE FIRST FLOOR. IT LOOKS LIKE SOMETHING FROM A SCIENCE FICTION MOVIE
A HUMAN ON THE SAME SCALE
RESTRICTED ACCESS BADGE REQUIRED
LET'S TAKE A LOOK AT THE EXPERIMENTS...
YES, THAT'S THE HEART OF THE MATTER!



ACCORDING TO THE EXPERIMENT BEING PLANNED, WE NEED NEUTRONS WITH PRECISE CHARACTERISTICS. WE USE A TOOL TO SELECT THEM: THE MONOCHROMATOR *
Alain, physicist
A monochromator * is a kind of mirror; it works exactly like a prism
Incident flux
Deflected neutron flux
NEUTRONS ARE SELECTED ACCORDING TO THEIR " COLOUR ", THAT IS, THEIR ENERGY.
THE NEUTRONS RESULTING FROM THE CHAIN REACTION ARE MUCH TOO ENERGETIC; OF THE ORDER OF MeV *
WHEN THEY LEAVE THE HEAVY WATER TANK, THEY ARE THERMALLY * AT AN ENERGY OF ABOUT 25 meV *, AN ENERGY COMPARABLE TO THAT OF EXCITATIONS * IN SOLIDS: PERFECT FOR WHAT WE WANT TO ANALYZE.
TO UNDERSTAND THE MATERIAL BETTER, YOU HAVE TO KNOW....
.... HOW THE ATOMS ARE ORGANIZED (THE STRUCTURE)
or
or
HOW THEY MOVE (THE EXCITATION *)
IN A SOLID, THE ATOMS * ARE BOUND TO EACH OTHER BY SMALL SPRINGS. THESE VIBRATE SPONTANEOUSLY WHEN HEATED. IF A NEUTRON IMPACTS AN ATOM, IT GAINS OR LOSES ENERGY, AND THE VIBRATION SPREADS TO THE NEXT ATOMS
In crystalline solids * (e.g quartz) the atoms vibrate around their equilibrium position.
In liquids, the atoms move while keeping the distances between neighbors.
Glass (a frozen liquid) is is an example of amorphous solid
The liquid crystals, a subset of the molecule * can be oriented
Polymers are long molecules like DNA

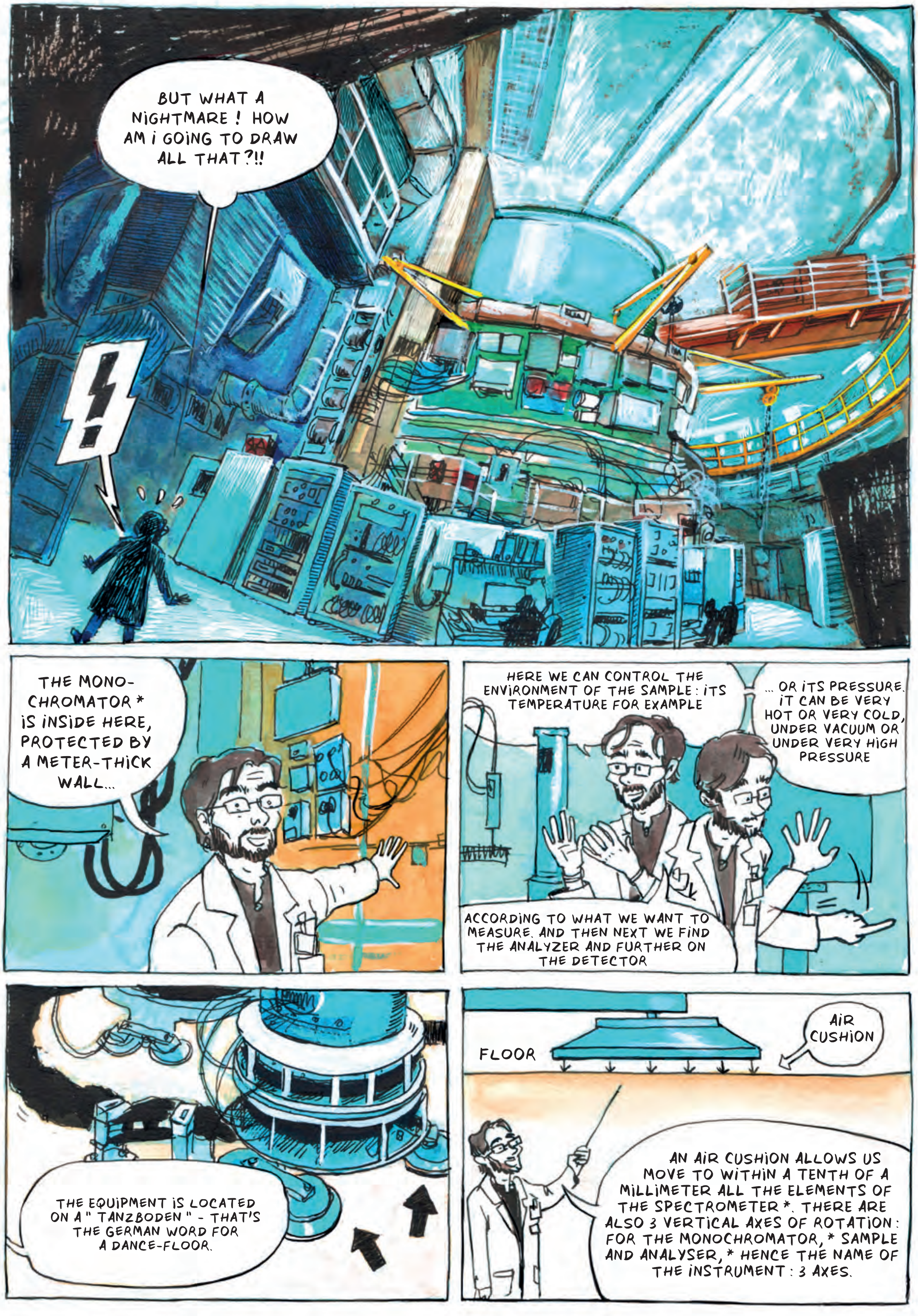


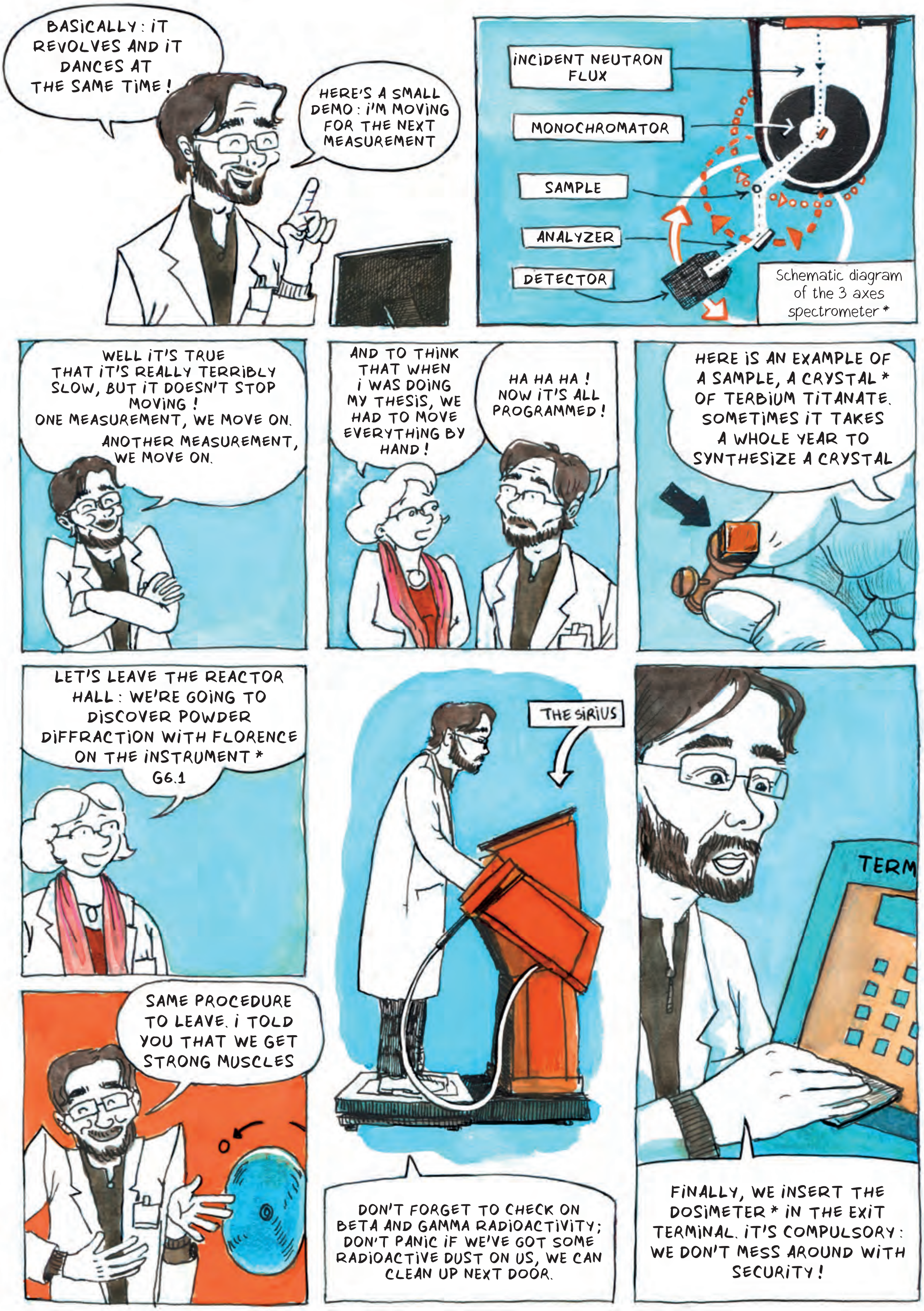
WE USE SEVERAL TECHNIQUES TO INVESTIGATE MATTER. WE CAN DESCRIBE THREE OF THEM BY SHOWING YOU SCHEMATICS OF THE SPECTROMETERS * AS SEEN FROM ABOVE, AND WITH AN EXAMPLE OF THE ASSOCIATED SPECTRUM WE OBTAIN AND THAT ALLOWS US TO READ THE RESULT.
Isabelle, Physicist
INELASTIC SCATTERING
We measure the energies gained or lost by the neutrons that impact the sample, to deduce how the atoms * vibrate.
Incident neutron flux
Sample
Monochromator
Analyzer
Detector
HERE WE SEE THE ELASTIC PEAK: THE NEUTRONS THAT HAVE NOT CHANGED ENERGY
ON BOTH SIDES THESE ARE INELASTIC PEAKS: NEUTRONS THAT HAVE GAINED OR LOST ENERGY
WITH THESE RESULTS, WE CAN DEDUCE HOW THE ATOMS VIBRATE!
DIFFRACTION
Neutron flow guided from the reactor
Cold neutron guide
Monochromator
Sample in its environment (furnace, cryostat ...)
Detector
THE NEUTRONS DIFFRACTED BY THE SAMPLE ARE COUNTED ACCORDING TO THEIR POSITION IN THE DETECTOR (THE DIFFRACTION ANGLE). IN A CRYSTAL *, WHERE THE ATOMS ARE WELL ARRANGED, WE CAN SEE PEAKS AT CERTAIN POINTS OF THE DETECTOR *
THESE ARE THE "BRAGG PEAKS" * THEY ALLOW US TO KNOW HOW ATOMS ARE ORGANIZED LOCALLY AND HOW THIS STRUCTURE IS REPRODUCED IN SPACE.
intensité
angle de diffraction
SMALL ANGLE NEUTRON SCATTERING
Speed selector
Sample
Detector
VERY SLOW NEUTRONS ARE USED. THE DETECTOR * IS A LONG WAY FROM THE SAMPLE, UP TO 20 METERS. WE NO LONGER SEE THE ATOMS BUT LARGER OBJECTS: MOLECULES * OR SETS OF MOLECULES
THIS DETECTOR * COLLECTS NEUTRONS SCATTERED IN TWO DIMENSIONS, VERTICAL AND HORIZONTAL. THE SPECTRUM OF A LIQUID CRYSTAL * FORMS A RING-SHAPED MARK

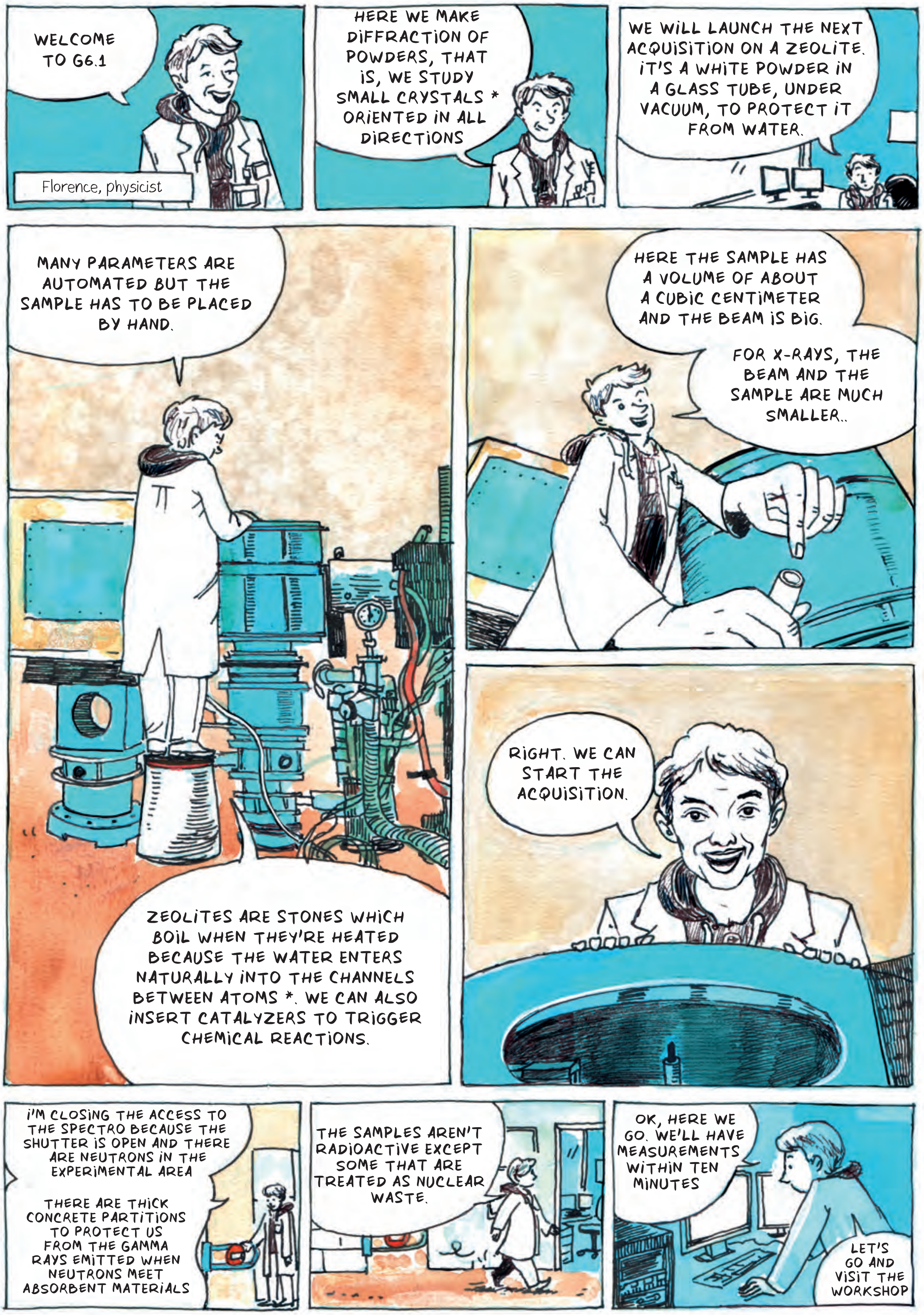


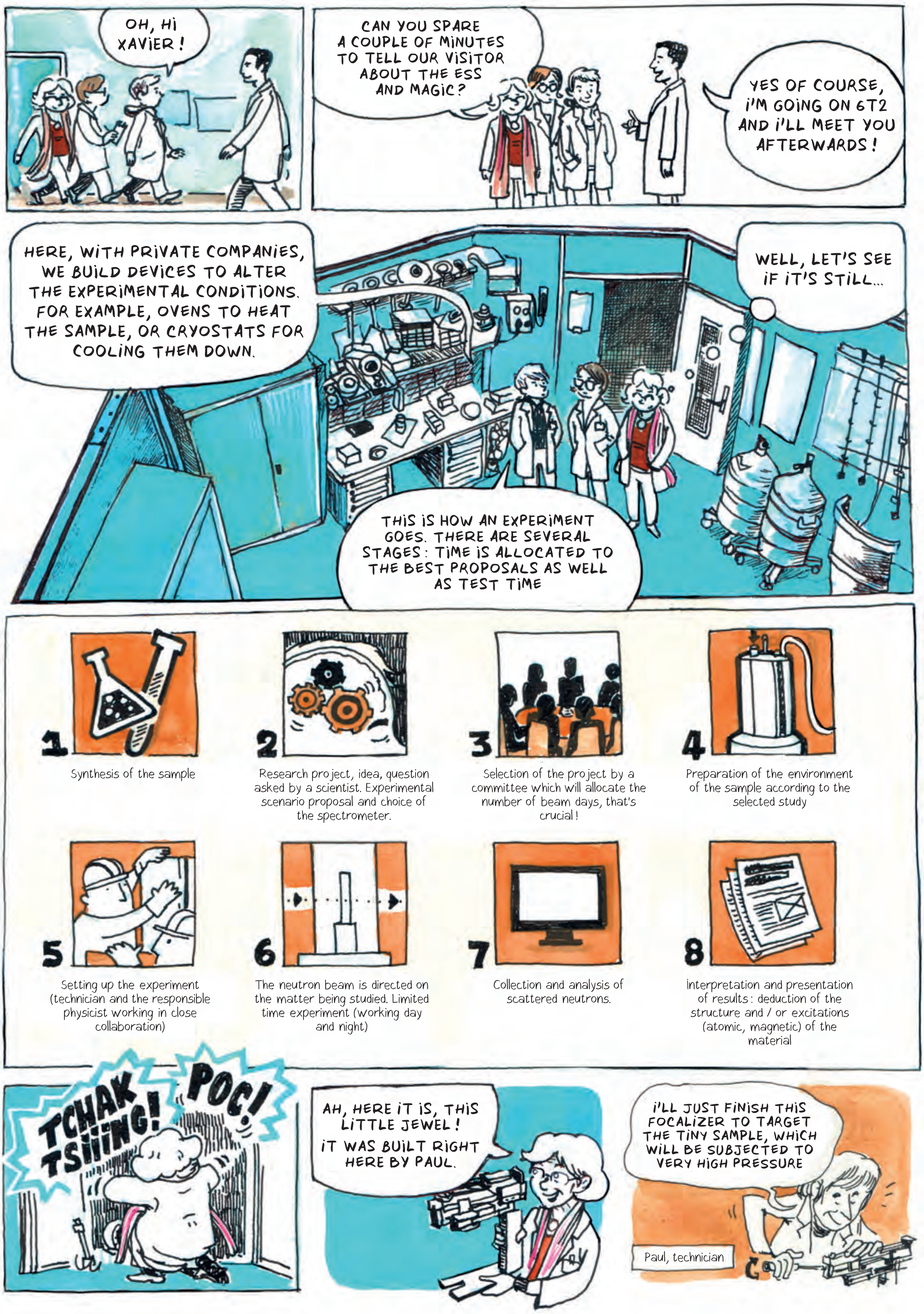
WE EXPLAIN TO YOU WHY...
NEUTRONS HAVE IT ALL
EVEN IF WE'RE JOKING, THIS SAYING IS WELL-KNOWN AND IT'S GENERALLY CORRECT
Nicolas, physicist
THE NEUTRON ALLOWS US TO DETERMINE:
The organization of atoms * and the position of each one
The individual and collective movements of atoms * and molecules *
The orientation and power of small magnets carried by atoms * in magnetic materials.
The neutron, both a wave...
wavelength
λ
When it encounters an obstacle, the incident plane wave gives rise to a spherical wave.
...and a particle
A compact object, located in space....
...whose path can be visualized.
And which can collide with other corpuscles.
THE NEUTRON IS VERY PENETRATING...
...IT'S NON-DESTRUCTIVE...
.... AND SENSITIVE TO MAGNETISM !
REALLY, EVERYTHING WE WANT !
HEY, DO YOU WANT TO COME WITH ME TO VISIT THE REACTOR HALL?

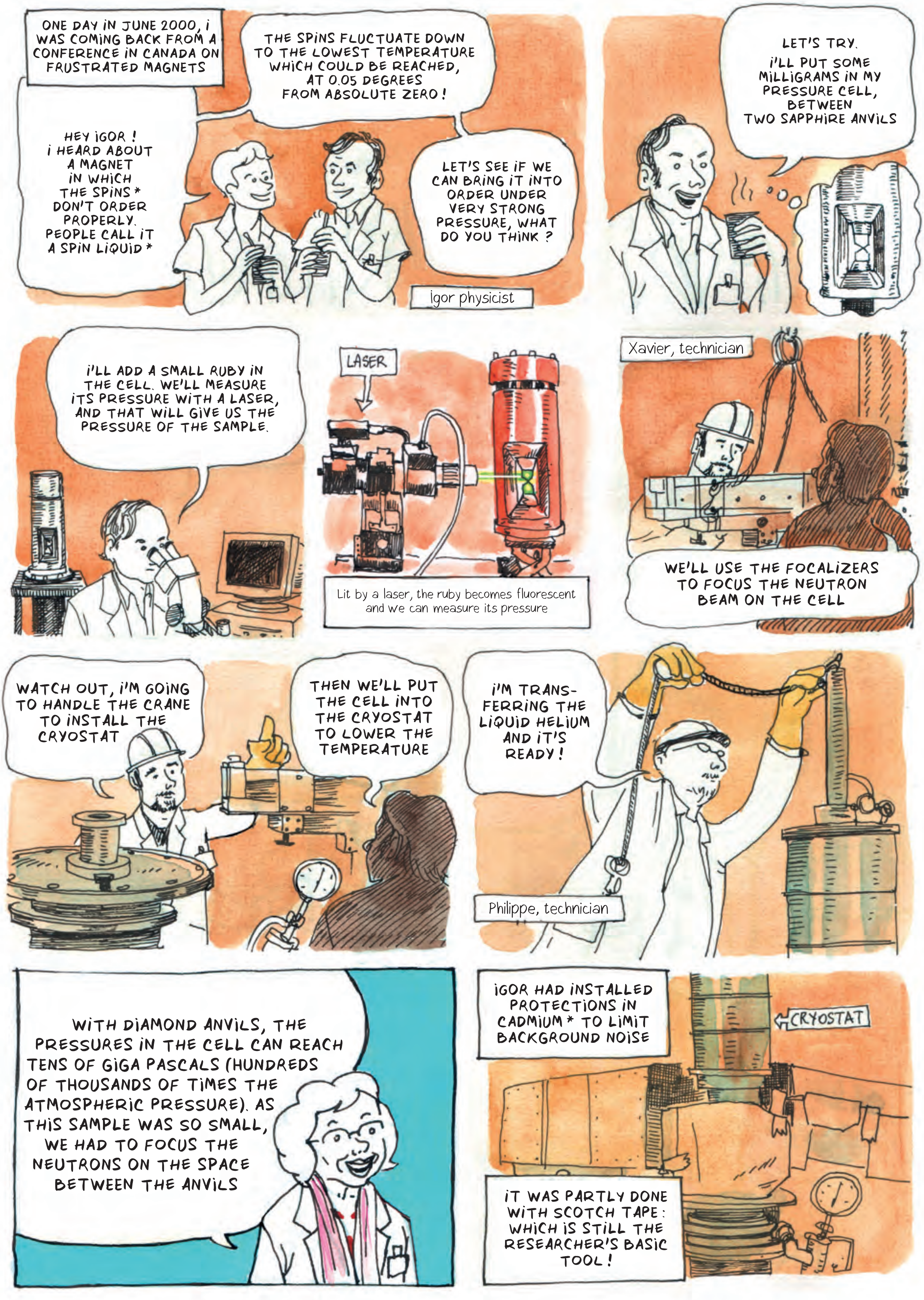

BEFORE PASSING THE AIRLOCK, YOU NEED TO ACTIVATE YOUR ELECTRONIC DOSIMETER * WHICH MEASURES HOW MUCH RADIATION YOU RECEIVE
Yvan, Physicist
TERMIN.
I HOPE YOU HAVEN'T GOT YOUR PHONE WITH YOU? BECAUSE THE SYSTEM HAS A NASTY HABIT OF INTERFERING WITH PHONES!
HERE GOES
AH YES, THAT'S THE SNAG: IF IT HAPPENS, WE'LL BE IN TROUBLE WITH SECURITY!
...
ACCORDING TO THE REGULATIONS, WE HAVE TO WEAR THE DOSIMETER * AT CHEST HEIGHT
... WHEN ALAIN GETS THROUGH, WE CAN ENTER THE AIRLOCK!
WHEN YOU INSERT YOUR CARD, AND YOU'RE ENTERING THE CODE, YOU MUSTN'T GO TOO FAST OR TOO SLOW, OTHERWISE YOU HAVE TO GO BACK AND START ALL OVER AGAIN!
TRY EXPLAINING THAT TO RESEARCHERS WHO DON'T SPEAK FRENCH OR ENGLISH
NOT TOO FAST AND NOT TOO SLOW
CAN WE MEET UP AGAIN AFTER THE VISIT, SO YOU CAN YOU TELL US ABOUT SONATE?
FINE BY ME
AND THEN THERE'S THIS DOOR TO BE OPENED, BECAUSE THE INTERIOR OF THE HALL IS PRESSURIZED. IT'S HEAVY: TRY IT
O
AH ...? YOU'RE RIGHT!
YOU STRENGTHEN YOUR MUSCLES WHEN YOU HAVE TO KEEP GOING IN AND OUT OF THE REACTOR HALL.... WHAT'S MORE, THERE ARE TWO DOORS!
O
F
YOU CAN OPEN THE SECOND ONE

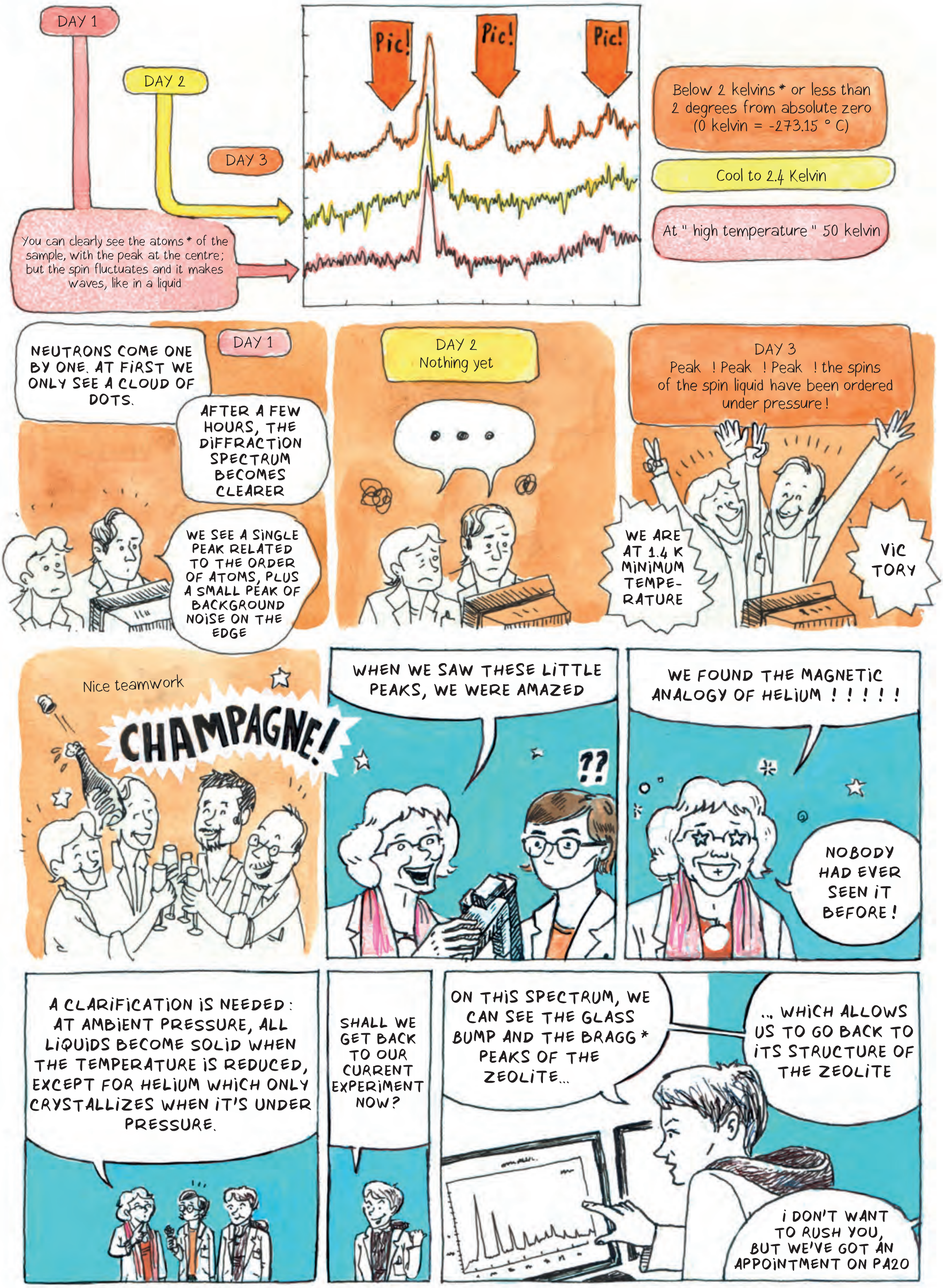

BUT WHAT A NIGHTMARE ! HOW AM I GOING TO DRAW ALL THAT ?!!
THE MONO-CHROMATOR * IS INSIDE HERE, PROTECTED BY A METER-THICK WALL...
HERE WE CAN CONTROL THE ENVIRONMENT OF THE SAMPLE : ITS TEMPERATURE FOR EXAMPLE
... OR ITS PRESSURE. IT CAN BE VERY HOT OR VERY COLD, UNDER VACUUM OR UNDER VERY HIGH PRESSURE
ACCORDING TO WHAT WE WANT TO MEASURE. AND THEN NEXT WE FIND THE ANALYZER AND FURTHER ON THE DETECTOR
THE EQUIPMENT IS LOCATED ON A " TANZBODEN " - THAT'S THE GERMAN WORD FOR A DANCE-FLOOR.
FLOOR
AIR CUSHION
AN AIR CUSHION ALLOWS US MOVE TO WITHIN A TENTH OF A MILLIMETER ALL THE ELEMENTS OF THE SPECTROMETER *. THERE ARE ALSO 3 VERTICAL AXES OF ROTATION : FOR THE MONOCHROMATOR, * SAMPLE AND ANALYSER, * HENCE THE NAME OF THE INSTRUMENT : 3 AXES.


BASICALLY: IT REVOLVES AND IT DANCES AT THE SAME TIME!
HERE'S A SMALL DEMO: I'M MOVING FOR THE NEXT MEASUREMENT
INCIDENT NEUTRON FLUX
MONOCHROMATOR
SAMPLE
ANALYZER
DETECTOR
Schematic diagram of the 3 axes spectrometer *
WELL IT'S TRUE THAT IT'S REALLY TERRIBLY SLOW, BUT IT DOESN'T STOP MOVING! ONE MEASUREMENT, WE MOVE ON. ANOTHER MEASUREMENT, WE MOVE ON.
AND TO THINK THAT WHEN I WAS DOING MY THESIS, WE HAD TO MOVE EVERYTHING BY HAND!
HA HA HA! NOW IT'S ALL PROGRAMMED!
HERE IS AN EXAMPLE OF A SAMPLE, A CRYSTAL * OF TERBIUM TITANATE. SOMETIMES IT TAKES A WHOLE YEAR TO SYNTHESIZE A CRYSTAL
LET'S LEAVE THE REACTOR HALL: WE'RE GOING TO DISCOVER POWDER DIFFRACTION WITH FLORENCE ON THE INSTRUMENT * G6.1
THE SIRIUS
TERM
SAME PROCEDURE TO LEAVE. I TOLD YOU THAT WE GET STRONG MUSCLES
DON'T FORGET TO CHECK ON BETA AND GAMMA RADIOACTIVITY; DON'T PANIC IF WE'VE GOT SOME RADIOACTIVE DUST ON US, WE CAN CLEAN UP NEXT DOOR.
FINALLY, WE INSERT THE DOSIMETER * IN THE EXIT TERMINAL. IT'S COMPULSORY: WE DON'T MESS AROUND WITH SECURITY!

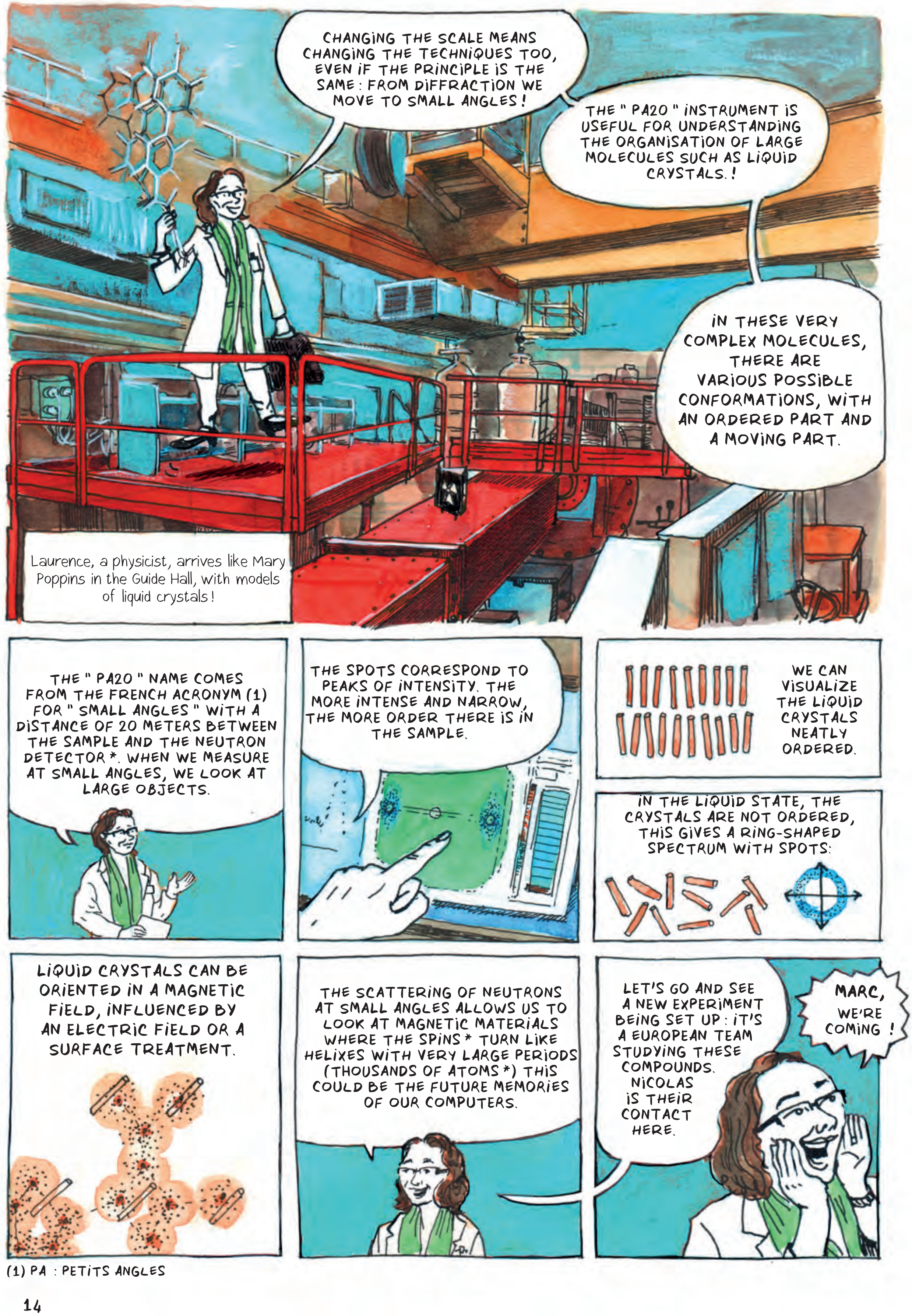

WELCOME TO G6.1
Florence, physicist
HERE WE MAKE DIFFRACTION OF POWDERS, THAT IS, WE STUDY SMALL CRYSTALS * ORIENTED IN ALL DIRECTIONS
WE WILL LAUNCH THE NEXT ACQUISITION ON A ZEOLITE. IT'S A WHITE POWDER IN A GLASS TUBE, UNDER VACUUM, TO PROTECT IT FROM WATER.
MANY PARAMETERS ARE AUTOMATED BUT THE SAMPLE HAS TO BE PLACED BY HAND.
HERE THE SAMPLE HAS A VOLUME OF ABOUT A CUBIC CENTIMETER AND THE BEAM IS BIG.
FOR X-RAYS, THE BEAM AND THE SAMPLE ARE MUCH SMALLER..
ZEOLITES ARE STONES WHICH BOIL WHEN THEY'RE HEATED BECAUSE THE WATER ENTERS NATURALLY INTO THE CHANNELS BETWEEN ATOMS *. WE CAN ALSO INSERT CATALYZERS TO TRIGGER CHEMICAL REACTIONS.
RIGHT. WE CAN START THE ACQUISITION.
I'M CLOSING THE ACCESS TO THE SPECTRO BECAUSE THE SHUTTER IS OPEN AND THERE ARE NEUTRONS IN THE EXPERIMENTAL AREA
THERE ARE THICK CONCRETE PARTITIONS TO PROTECT US FROM THE GAMMA RAYS EMITTED WHEN NEUTRONS MEET ABSORBENT MATERIALS
THE SAMPLES AREN'T RADIOACTIVE EXCEPT SOME THAT ARE TREATED AS NUCLEAR WASTE.
OK, HERE WE GO. WE'LL HAVE MEASUREMENTS WITHIN TEN MINUTES
LET'S GO AND VISIT THE WORKSHOP


OH, HI XAVIER!
CAN YOU SPARE A COUPLE OF MINUTES TO TELL OUR VISITOR ABOUT THE ESS AND MAGIC?
YES OF COURSE, I'M GOING ON 6T2 AND I'LL MEET YOU AFTERWARDS!
HERE, WITH PRIVATE COMPANIES, WE BUILD DEVICES TO ALTER THE EXPERIMENTAL CONDITIONS. FOR EXAMPLE, OVENS TO HEAT THE SAMPLE, OR CRYOSTATS FOR COOLING THEM DOWN.
WELL, LET'S SEE IF IT'S STILL...
THIS IS HOW AN EXPERIMENT GOES. THERE ARE SEVERAL STAGES: TIME IS ALLOCATED TO THE BEST PROPOSALS AS WELL AS TEST TIME
1
Synthesis of the sample
2
Research project, idea, question asked by a scientist. Experimental scenario proposal and choice of the spectrometer.
3
Selection of the project by a committee which will allocate the number of beam days, that's crucial!
4
Preparation of the environment of the sample according to the selected study
5
Setting up the experiment (technician and the responsible physicist working in close collaboration)
6
The neutron beam is directed on the matter being studied. Limited time experiment (working day and night)
7
Collection and analysis of scattered neutrons.
8
Interpretation and presentation of results: deduction of the structure and / or excitations (atomic, magnetic) of the material
TCHAK TSIIING!
POC!
AH, HERE IT IS, THIS LITTLE JEWEL! IT WAS BUILT RIGHT HERE BY PAUL.
I'LL JUST FINISH THIS FOCALIZER TO TARGET THE TINY SAMPLE, WHICH WILL BE SUBJECTED TO VERY HIGH PRESSURE
Paul, technician

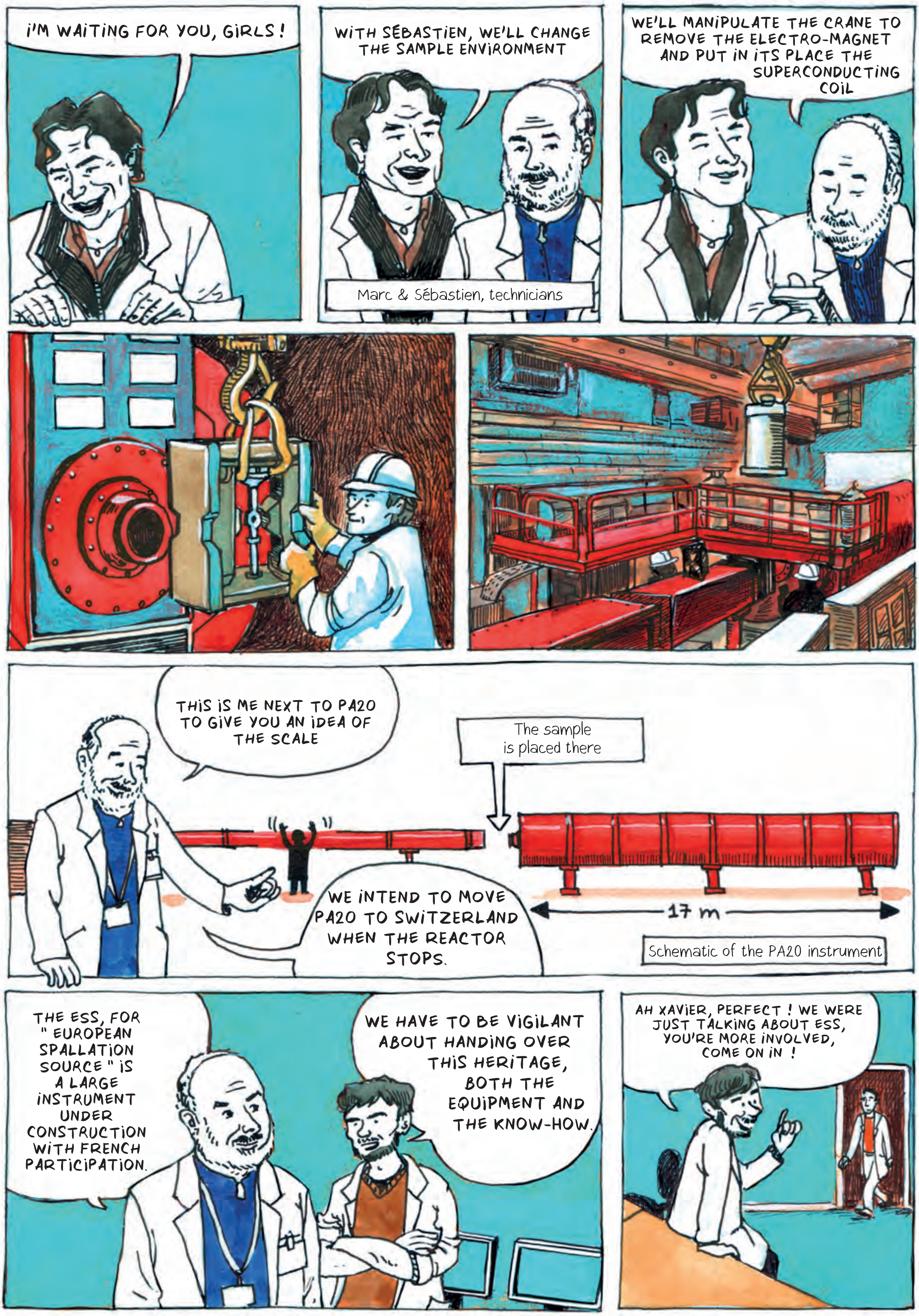

ONE DAY IN JUNE 2000, I WAS COMING BACK FROM A CONFERENCE IN CANADA ON FRUSTRATED MAGNETS
HEY IGOR! I HEARD ABOUT A MAGNET IN WHICH THE SPINS* DON'T ORDER PROPERLY. PEOPLE CALL IT A SPIN LIQUID*
THE SPINS FLUCTUATE DOWN TO THE LOWEST TEMPERATURE WHICH COULD BE REACHED, AT 0.05 DEGREES FROM ABSOLUTE ZERO!
LET'S SEE IF WE CAN BRING IT INTO ORDER UNDER VERY STRONG PRESSURE, WHAT DO YOU THINK?
Igor physicist
LET'S TRY. I'LL PUT SOME MILLIGRAMS IN MY PRESSURE CELL, BETWEEN TWO SAPPHIRE ANVILS
I'LL ADD A SMALL RUBY IN THE CELL. WE'LL MEASURE ITS PRESSURE WITH A LASER, AND THAT WILL GIVE US THE PRESSURE OF THE SAMPLE.
LASER
Lit by a laser, the ruby becomes fluorescent and we can measure its pressure
Xavier, technician
WE'LL USE THE FOCALIZERS TO FOCUS THE NEUTRON BEAM ON THE CELL
WATCH OUT, I'M GOING TO HANDLE THE CRANE TO INSTALL THE CRYOSTAT
THEN WE'LL PUT THE CELL INTO THE CRYOSTAT TO LOWER THE TEMPERATURE
I'M TRANSFERRING THE LIQUID HELIUM AND IT'S READY!
Philippe, technician
WITH DIAMOND ANVILS, THE PRESSURES IN THE CELL CAN REACH TENS OF GIGA PASCALS (HUNDREDS OF THOUSANDS OF TIMES THE ATMOSPHERIC PRESSURE). AS THIS SAMPLE WAS SO SMALL, WE HAD TO FOCUS THE NEUTRONS ON THE SPACE BETWEEN THE ANVILS
IGOR HAD INSTALLED PROTECTIONS IN CADMIUM* TO LIMIT BACKGROUND NOISE
CRYOSTAT
IT WAS PARTLY DONE WITH SCOTCH TAPE: WHICH IS STILL THE RESEARCHER'S BASIC TOOL!



DAY 1
DAY 2
DAY 3
You can clearly see the atoms * of the sample, with the peak at the centre; but the spin fluctuates and it makes waves, like in a liquid
Pic!
Pic!
Pic!
Below 2 kelvins * or less than 2 degrees from absolute zero (0 kelvin = -273.15 ° C)
Cool to 2.4 Kelvin
At " high temperature " 50 kelvin
NEUTRONS COME ONE BY ONE. AT FIRST WE ONLY SEE A CLOUD OF DOTS.
DAY 1
AFTER A FEW HOURS, THE DIFFRACTION SPECTRUM BECOMES CLEARER
WE SEE A SINGLE PEAK RELATED TO THE ORDER OF ATOMS, PLUS A SMALL PEAK OF BACKGROUND NOISE ON THE EDGE
DAY 2
Nothing yet
...
DAY 3
Peak ! Peak ! Peak ! the spins of the spin liquid have been ordered under pressure !
WE ARE AT 1.4 K MINIMUM TEMPE-RATURE
VIC TORY
Nice teamwork
CHAMPAGNE!
WHEN WE SAW THESE LITTLE PEAKS, WE WERE AMAZED
??
WE FOUND THE MAGNETIC ANALOGY OF HELIUM ! ! ! ! !
NOBODY HAD EVER SEEN IT BEFORE !
A CLARIFICATION IS NEEDED : AT AMBIENT PRESSURE, ALL LIQUIDS BECOME SOLID WHEN THE TEMPERATURE IS REDUCED, EXCEPT FOR HELIUM WHICH ONLY CRYSTALLIZES WHEN IT'S UNDER PRESSURE.
SHALL WE GET BACK TO OUR CURRENT EXPERIMENT NOW?
ON THIS SPECTRUM, WE CAN SEE THE GLASS BUMP AND THE BRAGG * PEAKS OF THE ZEOLITE...
... WHICH ALLOWS US TO GO BACK TO ITS STRUCTURE OF THE ZEOLITE
I DON'T WANT TO RUSH YOU, BUT WE'VE GOT AN APPOINTMENT ON PA20



(1) PA : PETITS ANGLES


I'M WAITING FOR YOU, GIRLS !
WITH SÉBASTIEN, WE'LL CHANGE THE SAMPLE ENVIRONMENT
Marc & Sébastien, technicians
WE'LL MANIPULATE THE CRANE TO REMOVE THE ELECTRO-MAGNET AND PUT IN ITS PLACE THE SUPERCONDUCTING COIL
THIS IS ME NEXT TO PA20 TO GIVE YOU AN IDEA OF THE SCALE
The sample is placed there
WE INTEND TO MOVE PA20 TO SWITZERLAND WHEN THE REACTOR STOPS.
17 m
Schematic of the PA20 instrument
THE ESS, FOR " EUROPEAN SPALLATION SOURCE " IS A LARGE INSTRUMENT UNDER CONSTRUCTION WITH FRENCH PARTICIPATION.
WE HAVE TO BE VIGILANT ABOUT HANDING OVER THIS HERITAGE, BOTH THE EQUIPMENT AND THE KNOW-HOW.
AH XAVIER, PERFECT ! WE WERE JUST TALKING ABOUT ESS, YOU'RE MORE INVOLVED, COME ON IN !


I AM IN CHARGE OF MAGIC, ONE OF THE SPECTROS * PARTLY FINANCED BY FRANCE WITHIN THE ESS. THE FIRST NEUTRONS ARE EXPECTED IN 2022
Xavier, engineer
The ESS will be based in Lund in Sweden: protons are accelerated over 600 m and hit a tungsten target where neutrons will tear off.
LUND
By measuring the arrival time of the neutron on the detector, we obtain its energy.
The ESS will emit pulsed neutrons - every 70ms - which will make it possible to use most of the neutrons emitted.
As a reminder, a reactor is used with a monochromator * and therefore we don't get all the other " colors " of neutrons
IT'S A HUGE TASK WITH INTERNATIONAL COLLABORATION DEVELOPING THE SOURCE AND THE LINES
...
ESS 2019
EVEN IF THE FRENCH BUILD SPECTROS, THEY WILL ONLY HAVE ACCESS IF THEY PAY THE RUNNING COSTS, AND THE TIME WILL BE VERY LIMITED
FOR MY PART, I MADE A SMALL CALCULATION AND BASICALLY: FRANCE WILL GO FROM SPENDING 5000 DAYS OF EXPERIMENTS PER YEAR (IN 2014) TO JUST 400 DAYS A YEAR WITH ESS ONLY
Alain, Physicist
TO COMPENSATE FOR THIS LACK OF TIME, WE PLAN TO BUILD A NATIONAL SOURCE, SONATE, ON THE SAME PRINCIPLE AS THE ESS...
... LESS POWERFUL ...
...TO GIVE NEUTRONS BACK TO FRANCE.
TO KEEP THE COMMUNITY ACTIVE
Team neutrons
AND TO PREPARE RESEARCHERS TO USE THE ESS
OLYMPIC SWIMMING POOL
ENTRY Limited Access
LIKE A HIGH LEVEL SWIMMER WHO NEEDS A MUNICIPAL POOL BEFORE USING THE OLYMPIC POOL!
It is predicted that when Orphée stops, we will lose 40 % of the French neutron time, and 90 % when the Grenoble reactor (ILL) stops.
Sonate project
Sonate will allow us to maintain a well trained national team

LET'S SCATTER NEUTRONS

Orphée, nuclear research reactor
Plateau of Saclay

Analyzer – mirror identical to monochromator (qv) to determine the energy of a scattered neutron

Atom – a basic component of matter (solid, liquid or gas). An atom is formed by a nucleus comprising protons and neutrons and a cloud of electrons

Babyline – Apparatus for detection of radiation emitted by an irradiated sample

Bragg peak – when a monochromatic neutron beam is diffracted by a crystal, its intensity is considerably increased in various directions: these are the Bragg peaks, characteristic of the crystal

Cadmium – metal which absorbs neutrons. It allows the control of a nuclear reaction, but can also protect experiments from surrounding emissions

Condensed matter – the atoms of matter, in solid or liquid state

Crystal - a solid in which the atoms are arranged in a regular pattern

Detector - a counter that detects neutrons. It is placed behind the sample

Dosimeter – worn on the chest, it measures the radiation received

Excitation – atoms vibrate faster as the temperature increases. This speed characterises excitations.

Kelvin - unit of temperature measurement, written as K. Absolute zero (0 K) corresponds to -273.15° Celsius

Molecule - collection of electrically neutral atoms; atoms are joined together by chemical links.

WHAT DO WE DO AT THE LEON BRILLOUIN LABORATORY (LLB)?

We study the arrangement of atoms, their vibrations or their magnetism in materials, by bombarding them with neutrons.

WHAT IS A NEUTRON?

A particle found in the core of atoms, which possesses a mass, a magnetic momentum (spin), but which doesn't have an electrical charge: it's " neutral ".

IS THAT A WAVE OR A PARTICLE?

It's both! The wavelength of the neutrons used in the experiments is in the order of magnitude of the distances between atoms (a few tenth of a billionth of a meter)

HOW DO WE PRODUCE NEUTRONS?

In the nuclear reactor, by nuclear fission, in the same way as in nuclear plants producing electricity.

WHAT'S THE EFFECT CALLED DIFFRACTION?

It's what happens when a neutron hits a material, and changes direction. The diffraction of neutrons shows us the organization of atoms.

AND DIFFUSION ?

A neutron hitting a material can either gain or lose energy. This is called inelastic scattering. It shows us how atoms vibrate.

WHAT IS THE UNIT OF MEASUREMENT OF ENERGY? IS IT meV? MeV?

The electron volt (eV) is a unit of energy measurement. The neutrons emitted in the reactor have energies in the order of ***millions*** electron-volts (or MeV). These neutrons are subsequently slowed down and their energy becomes the same as atomic vibrations, several ***thousandths*** of an electron-volt (meV)

WHAT IS THE SPEED OF A NEUTRON?

A " thermal " neutron, whose energy is around 25 meV, moves at a speed of 1.8 km per second. The reactor also produces cold neutrons (slower) and hot (faster)

IS THIS DANGEROUS?

Neutrons are highly penetrating. Captured in certain materials, they become radioactive. Captured by the human body, they can destroy cells or cause cancers. Hence the need to protect yourself. However, you can also use neutrons to destroy cancerous tumors.

WHAT ARE THE APPLICATIONS IN OUR DAILY LIFE?

Understanding the atomic structure of materials allows us to discover new uses. This could be electronics, biology, chemistry, polymers or liquid crystals, magnetism. We can also obtain images of materials for the nuclear or aerospace industries, we can study the composition of a wine or understand the melting of chocolate.

Monochromator – mirror reflecting part of a neutron beam and allowing the selection of energy (speed and wavelength) of the reflected beam.

Spallation source - particles (protons) hit the atoms of a target at high speed, tearing apart its constituents, producing neutrons

Spectrometer – instrument which selects a beam of neutrons, directs them on to the sample being studied, and collects the diffracted neutrons.

Spin - the intrinsic property of a particle, such as mass or electric charge, and characterizing its magnetism. It is a quantum object, but in condensed matter, the spin of magnetic atoms is often presented by a vector, such as a compass or a small magnet. The spin of the neutrons interacts with the spins of the atoms, which allows us to know their value, their orientation, and their vibration in the material being studied.

Spin Liquid – magnetic material in which the spins fluctuate, without being completely independent: the relative orientations of the spins of neighboring atoms are correlated, like the positions of atoms of a liquid, where atoms move but neighboring atoms remain at the same distance.

Time of flight - we measure the time taken by a neutron scattered by the sample to reach the detector, which is located at a specific distance. This allows us to calculate the speed, and hence the energy of the scattered neutrons.

Thermalize - Neutrons are thermalized at the exit of the reactor core, and lose energy. The energy of thermal neutrons is the ambient temperature (300 K or 25° Celsius, or around 25 meV). That of cold neutrons, slower, is around 2 meV or 20 K. That of hot neutrons, faster, is around 120 meV or 1400 K.