Science & Technology Facilities Council

Technical Report

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Investigation and documentation of ancillary plant of ISIS

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1. Abstract

During the last ten months an internship has been carried out in ISIS, a pulsed neutron and muon source located at the Rutherford Appleton Laboratory in the United Kingdom.

The objectives of the project have been the retrieval of plant information: from old drawings and on site measurements, and the update of the same for future use: generation of 3D models and new drawings. It has also been an important part of the project to redesign a room that is part of the water system plant, providing a new solution that will solve the actual problems, that were identified during the project

This document is composed of the following chapters. The first one is the general explanation of ISIS, in order to locate the project and the facility. The second is the description of the cooling system and of the tunnel located in the R55 building, providing the updated schemes and 3D models. After these, the studied of the layout and the redesign of a plant room and finally a brief conclusion of the project that has been done.

2. Acknowledgement

First of all I would like to thank the Rutherford Appleton Laboratory for giving me the opportunity to carry out an internship in this prestigious scientific facility. Special thanks to Mr Matt Fletcher and my manager, Mr Trevor Pike and my work colleagues, Mr John Corkhill and Mr Duncan Couchman, for helping me along those ten months. I do not want to forget either the Prof. Felix Fernandez Alonso, leader of the molecular spectroscopy group, who gave me a hand with some scientific aspects.

I wish to express my gratitude to Mondragon Unibertsitatea for giving me the chance to develop the final step of my degree in a foreign country, as well as for providing me the grant to make life easier. I would also like to thank my tutor Dr. Jose Alberto Eguren for his guidance in this project, it has been very useful.

My appreciations also to my friends, with special mention to Irati for her patience with the corrections during the last few weeks and also to Alberto for helping me during my stay in the UK.

Finally, I would like to show my gratitude to my family for their supporting and for making it possible. Special thanks to my brother Lander for helping me with the project and for giving me the chance to live this experience.

Thank you very much, eskerrik asko!

3. Index

4. Problematic issues

Two main problematic issues were faced during the internship.

The first one was due to the modifications that were done in the facility over many years. As the facility was built during the late 1970's and early 1980's, many improvements and changes have been carried out to keep ISIS in good condition until today. Some of these adjustments were not updated in the data base. Consequently, the schemes of the system did not show the real circuits and this would be a setback, if the drawings were needed for any maintenance or other type of operation.

The second problem was located in a pump room placed in the Target Station 2 (TS2). This room was designed by installing the machineries from the outside TS2 building to the inside. This happened because the room was built while the TS2 was being built, so the building did not have the main walls. As a result, if a change had to be done in the room, the layout, nowadays, would be a problem.

5. Objectives

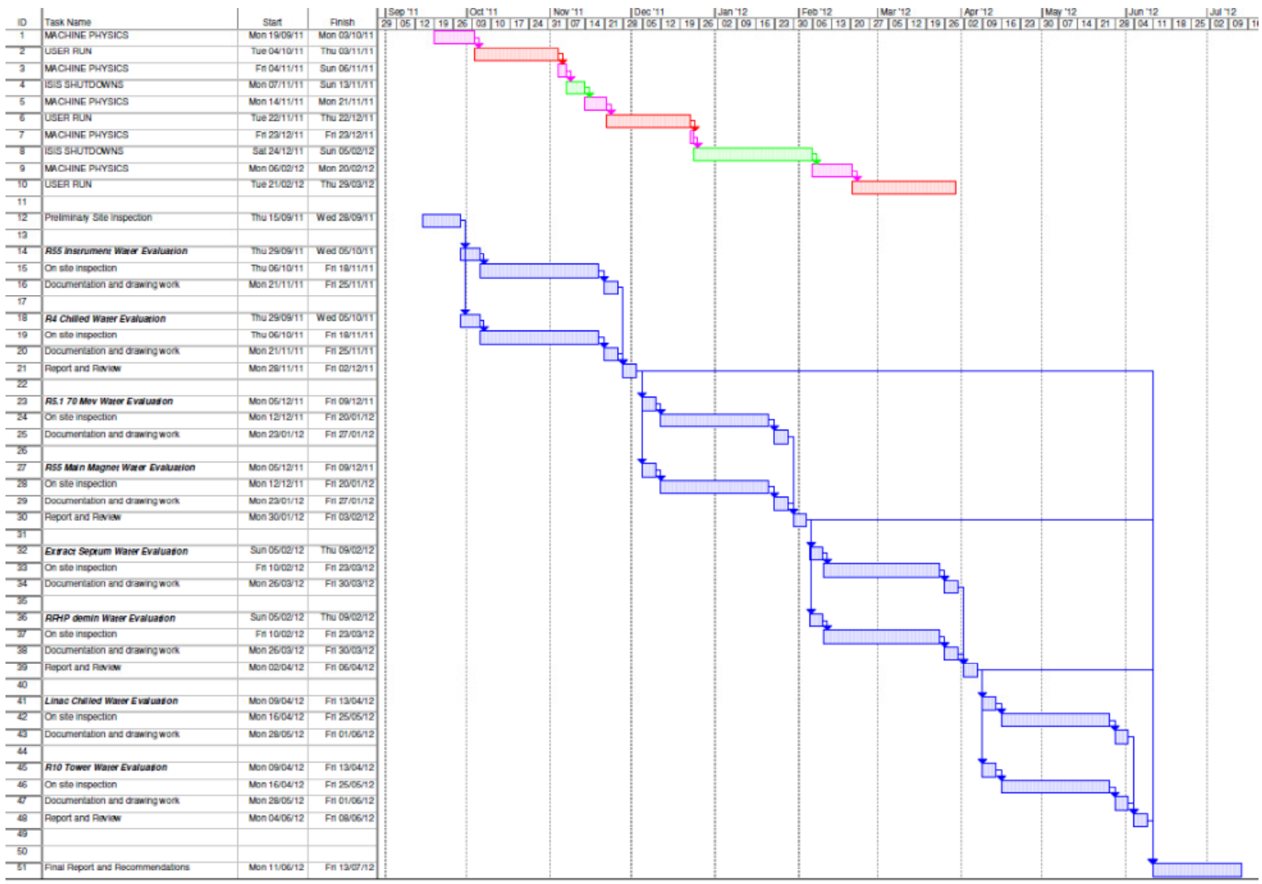
As there were two problematic issues, there were also two objectives, one for each problem.

The first objective, linked with the changes done in the facility, was to collect documents and information about the new circuits. With this data, new drawings and 3D models had to be created. Accordingly, the data base would be updated so workers could develop their tasks much better, which is the main objective.

The second objective is to improve the layout of the pump room located in the TS2 building. The modifications need to create a better layout so that changing the equipment is easier, the security of the room improves and the drainage system works better.

6. Project timeline

The phases of the project are explained in the Gantt Diagram shown below. These phases were assigned at the beginning of the internship, so some of them have been interchanged for other tasks during the year.



The updated circuits, systems or building were carried out in the next order:

- Cooling system R4 (Scheme and 3D model).
- Cooling circuit R5.1 (Scheme and 3D model).
- Air compressed R55 (Scheme).
- Tower water system R10, R11 and R4 (Scheme).
- Tunnel R4 (3D model).

- Tunnel R55 (3D model).

All these tasks were carried out with the similar phases described below. Firstly, some information was gathered and also old drawings of the area which had to be updated. When familiarized with the area, the second step was to go to the facility or the building and to take some notes and measures to be able to create the 3D model with the software.

When the drawing was finally finished, the drawing was checked in the area. Once the checking was correct, the next step was the numbering, the renaming and getting more information about the different elements and instruments. Following this procedure the drawing finally is as accurate as possible.

The task that does not appear in the Gantt is the redesign of the layout of a pump room. It was carried out in the second half of the year, after finishing the updating tasks.

In the redesign there were three different phases. The first step was to collect information and drawings of the room to understand how the room works. Once the function and equipment of the room were known, the next action was to find the particular problems of the area. When the issues were analyzed, more than one solution was considered to improve the room. Finally, the most suitable answers were chosen and the new layout and the improvements were transfer to the 3D model.

The last job was to gather all the developed tasks and to put them into this technical document.

7. ISIS neutrons and muons source

7.1. What is ISIS

ISIS is a scientific instrument which is a source of pulsed neutrons and muons. ISIS is located at the Rutherford Appleton Laboratory (RAL) on the Harwell Science and Innovation Campus in Oxfordshire, United Kingdom. It focuses on the scientific research of diverse science areas such as physics, chemistry, materials engineering, earth sciences, biology and archaeology. These experiments are executed using muon spectroscopy and neutron scattering techniques. These techniques probe the structure and dynamics of condensed matter on a microscopic scale, ranging from the subatomic to the macromolecular.

Figure 1: Harwell Science and Innovation Campus.

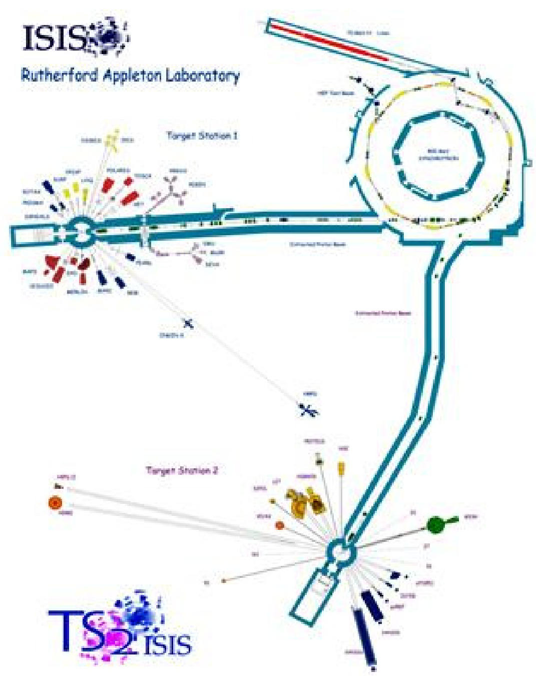
ISIS is part of RAL which at the beginning was the Rutherford High Energy Laboratory (RHEL). It was operated by The National Institute for Researching in Nuclear Science (NIRNS) formed in 1957. RHEL was established next to the old Atomic Energy Research Establishment which transferred a 600MeV proton linear accelerator to the new laboratory becoming a national facility for particle physics called Nimrod. Nowadays, RAL is home to many facilities which are itemized next:

- ISIS, the neutron and muon source.

- The Central Laser Facility which provides access to large scale laser system.
- The Microelectronics Support Centre (MSC).
- The National Grid Service (NGS) which develop within UK a production quality computing grid.
- Energy Research Unit.
- Space science.

All these facilities have contributed to RAL becoming one of the best laboratories in the UK. Moreover, the synchrotron Diamond Light Source is located on the same campus as RAL, adding even more importance to the entire campus.

Focusing on ISIS, the instrument was approved in 1977 and it was built using recycled components from Nimrod and Nina accelerators. The new facility, ISIS, was built from both accelerators. The first proton beam was produced in 1984, and the facility was formally opened by the then Prime Minister Margaret Thatcher in October 1985. In those years the facility comprised of the linear particle accelerator (Linac), the Synchrotron and Target Station 1, but in 2003 they started to build the new Target Station 2, which was completed in 2006.



The Linac is the first stage where the negatively charged hydrogen ions (H^-) are produced and after they are accelerated linearly inside the Linac, they are then sent into the synchrotron. The ion source is in charge of producing the ions and they are immediately accelerated and separated into bunches in the Radio Frequency Qaudrupole (RFQ). Here the ions are accelerated to 665 KeV and after this process they go into the linear accelerator where they are accelerated to 37% of the light speed to go into the synchrotron.

Before entering the synchrotron the hydrogen ions are stripped of their electrons by passing through a thin Aluminium Oxide foil, to become protons. After this happens the proton beam is accelerated through the synchrotron until it gets to 84% of the light speed. Then it is guided into both targets using magnets.

Finally, when the beam reaches both target stations it collides with a heavy tungsten metal target. When the protons impact into the target, neutrons spall out of the tungsten atoms creating the neutron source.

The neutrons are channelled through guides, or beamlines, to about 20 instruments in both targets. It is in these instruments where all the experiments are done using the neutrons. Muons are also generated in Target Station 1. They are produced a few meters before reaching the tungsten target when the beam collides with the carbon target.

7.2. How ISIS works

ISIS has two different areas, the engineering side and the scientific side. The combination of these two areas makes ISIS work efficiently. In the engineering side, normally, the work comprises designing new instruments, fixing or redesigning the old instruments, attending to the scientists' requirements, etc. On the other hand, in the scientific side, scientists carry out experiments and do research in many different areas. They normally work with the equipment designed by the engineers.

Another thing that ISIS does is hiring out the instruments. It hires instruments to private companies or to other laboratories which are not able to acquire this technology to carry out their research.

7.2.1. Technologically

ISIS develops the main work in both target stations, TS1 and TS2. In these areas are located all the instruments which are used by the scientist. These instruments are designed by different groups, the main ones have been designed by the ISIS engineers and some parts, vac tanks and special apparatus, have been designed by external engineers from all around the world. Normally, the manufacture of the instruments is done by private firms and the installation is carried out by ISIS.

Once the instrument is assembled and tested by the engineers in the target station, the scientists can start using them for their research. Depending on the application, different techniques will be used such as:

- Neutron diffraction.
- Neutron spectroscopy.
- Reflectometry.
- Small angle scattering.
- Muon spectroscopy.

As these techniques are different from each other, the different processes give different kinds of information. Consequently, depending on the specifications that the scientists have and the result that they want to find, the researchers have to choose the most appropriate instrument.

7.2.2. Economically

ISIS is administrated and operated by the Science and Technology Facilities Council (STFC). The economic support is done in a high percent by the UK government as well as by different countries.

Also experimental time is open to academic users from funding countries and is applied for through a twice-yearly “call for proposals”. Research allocation, or “beam-time”, is allotted to applicants via a peer-review process. Users and their parent institutions do not pay for the running costs of the facility, which are as much as £11,000 per instrument per day.

7.3. Definition of Linac, Synchrotron, Target Station 1, Target Station 2

As mentioned before, the laboratory has a few different parts to carry out the neutron and muon sources. These could be separated in 4 different areas, in reference of the work and the purpose that they have. These are the different areas: Linac, Synchrotron, Target Station 1 and Target Station 2.

7.3.1. Linac

In the area where the Linac is located there are three different parts as described before: Ions source, RFC and linear accelerator.

The source is of the magnetron type, comprising a molybdenum anode and cathode between which a low pressure hydrogen discharge is struck. The basic construction is shown in figure 3, where Hydrogen and Cesium are fed into the discharge via holes in the anode. The anode and cathode are housed in the stainless steel source body. At the top of the source the 0.6 x 10 mm extraction slit is located which is used to extract the ions from the source.

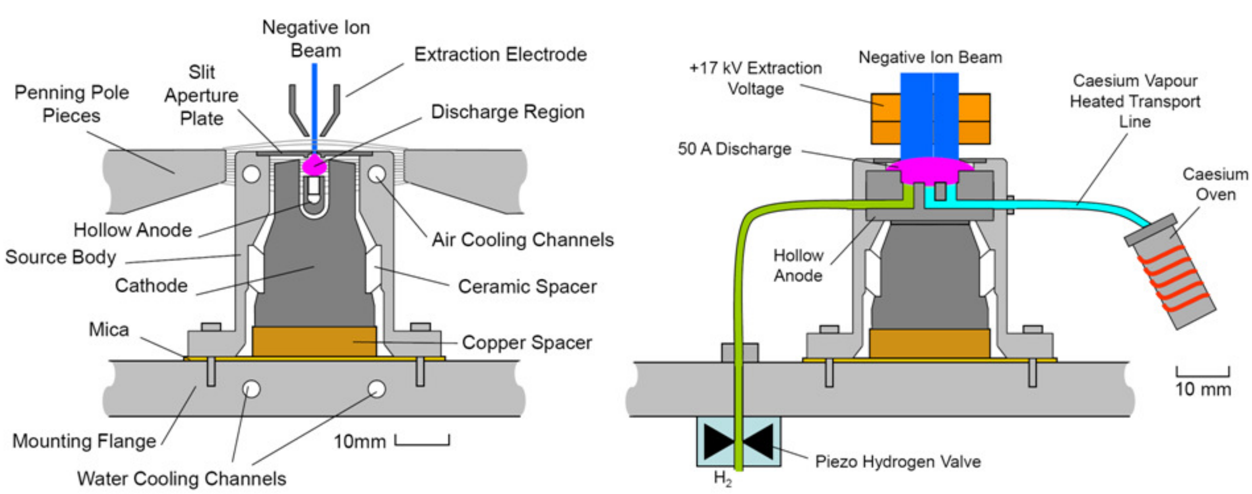


Figure 3: Ion Source explanation.

The operational source runs in pulsed mode with a 1% duty cycle. The timing for the source runs as follows: First a piezoelectric valve in the base of the source opens for approximately 200 µs to inject Hydrogen gas. This takes about 600 µs to reach the discharge region through holes in the anode and after this time the 50 A discharge current is turned on. The discharge takes approximately 250 µs to stabilize before the +17 kV extraction voltages is turned on and negative ions are extracted. The discharge current and extraction voltage are turned off together at the end of the pulse.

After the extraction the beam is bent through 90° and then further accelerated to 35 keV. The 90° bend analyzes out all the electrons and negatively charged molecular Hydrogen leaving only H^- ions (a hydrogen + 2 electrons), and this happens because the 90° Sector magnet is programmed to bend just the H^- beam electromagnetically into the wanted way. It is possible because the programming is specifically created to the H^- mass and also to the electrical charge. The analyzing magnet sits in a refrigerated box, which serves as a Cesium trap to prevent Cesium vapor entering the next stage of the accelerator. The magnet also enlarges the beam in the horizontal direction so that the slit extracted beam is expanded to have an equal aspect ratio after post acceleration.

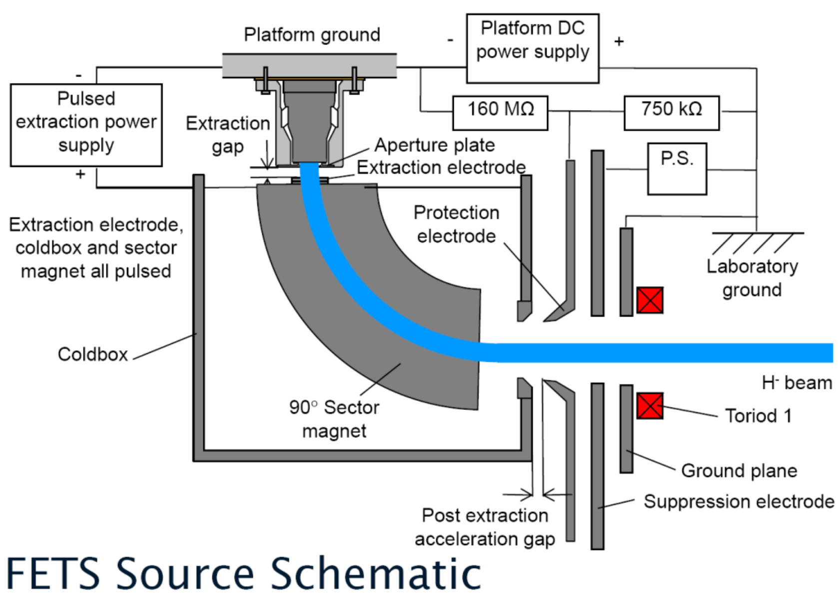


Figure 4: Ion Source schematic.

When the beam leaves the source it goes into the RFQ where it uses the intense radio frequency to focus, bunch and accelerate particles because it is particularly well suited for use with low velocity ions. Here the molecules are accelerated and focused by the four specially shapes electrodes which produce an alternating gradient quadrupole electric field. It operates at 665 keV and 202.5 MHz with which get acceleration of up to 4% of speed of light. The acceleration is made, like in all the circuit, with the help of the charge of the ions.

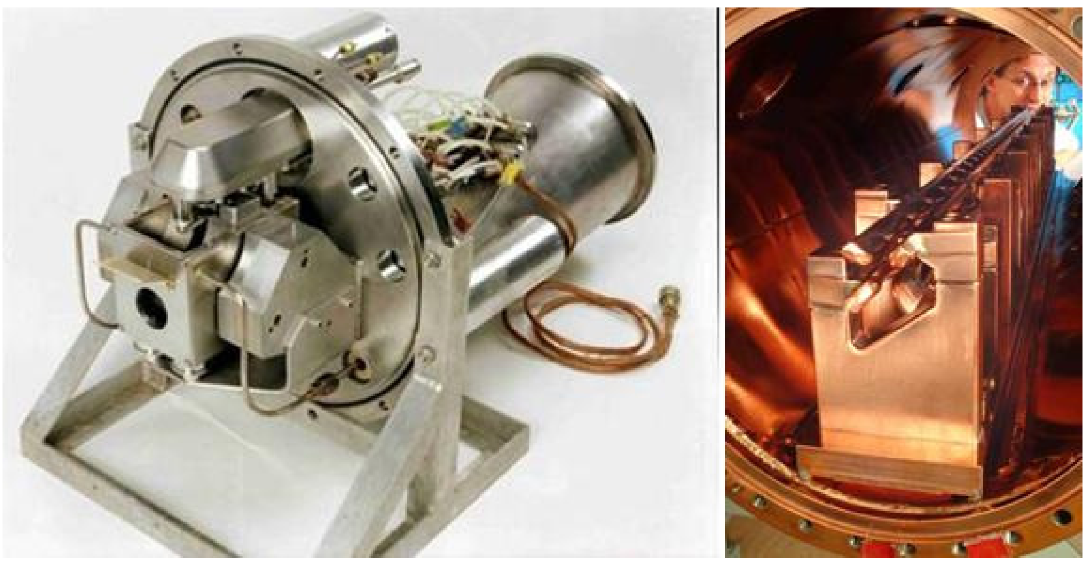


Figure 5: Ion source and RFQ.

This is an essential instrument in the circuit because it gives to the beam the energy and the speed that the beam needs to get into the next steep, the Linear Accelerator. This requirement is set by the Linear Accelerator which, in order to work, ti needs more energy in the beam than the Ion source could give. As before was told, the Ion source gives 35 keV, but the Linear Accelerator needs at least 665KeV, so this energy difference is given by the RFQ.

After the RFQ, as previously mentioned, comes the Linear Accelerator. This consists of four accelerating tanks in which high intensity radio-frequency (RF) fields accelerate the beam to 70 MeV.

This is the oldest instrument in ISIS. It was built in 1956 by the Metropolitan Vickers Company in Manchester but it still works perfectly. It is also the first part of the facility which is totally buried under hundreds of tonnes of concrete shielding blocks (as seen in the next figure 6). These blocks are required to shield workers from the high doses of X-rays and radiation produced during the normal operation of the accelerator.

Each linac tank has an outer steel wall, which forms a vacuum vessel, and an inner copper liner. It is made of copper to allow high frequency currents to resonate. The resonating currents produce the high voltages that kick the beam faster and faster, accelerating the beam until the amount which was told before. The vacuum is also very important because it allows the beam to progress without interferences and obstacle, as in the way of the beam there will not be any other material other than the H^- ions.

Figure 6: Linear accelerator inside and outside.

When the beam leaves the RFQ, the H^- enters the tank and travels along the axis where it meets a series of drift tubes. This drift tube is a series of tube shaped electrodes. The beam passes along the centre of the tubes and as it passes between neighbouring tubes it sees a voltage that gives it a kick. Packed inside each tube are electromagnets that squeeze the beam to keep in together. The linac provides 200µs long, 22 mA H^- pulses which are transported into the synchrotron. Final acceleration of the beam occurs in the synchrotron.

7.3.2. Synchrotron

The synchrotron is the last step in the acceleration of the ions, now protons. It accelerates the beam from 70 MeV until 800 MeV, which is more or less 84% of the speed of light and its radius is twenty six meters.

The synchrotron is an extremely complicated machine. However, it all comes down to some very simple physics. The only thing which has to be done to accelerate charged particles is put them in an electric field, and if the facility needs more speed, increasing the electric field will be enough. But since the synchrotron is circular, the beam should be bent in order to make the circuit successfully. To carry out this bend a magnetic field has to been put into the beam. As has been told before with the electric field, the stronger the magnetic field is, the more the beam will be bent. Those are really the two pieces of physics the whole accelerator is based on.

To carry out the task of the synchrotron there are four different types of instruments, most of them are magnets to put the magnetic field into the particles and the others are radio frequency (RF) components. Inside the group of magnets three other different magnets can be found: Dipole magnets, quadrupole magnets and trim quadrupoles.

The ten dipole magnets, which can be found around the synchrotron, are used to bend the beam round in a circle with theirs magnetic field. This field is 10.000 times stronger than the magnetic field produced by the Earth. Also it must be said that these magnets are really quite big, as each one weighs 33.5 tonnes, is 4.5 meters long, and 1.8 meters high.

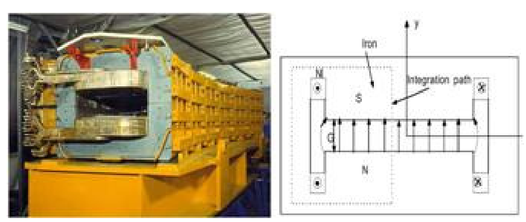


Figure 7: Dipole

The quadrupole magnets are used to focus the particles back onto the centre of the beam. This focussing is a real necessity because the beam is composed of protons, and every proton has exactly the same charge, so

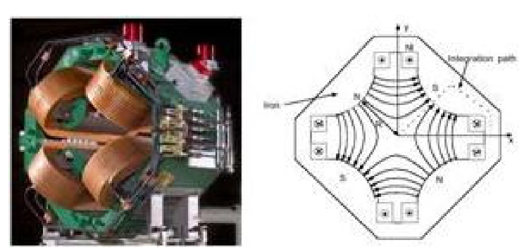


Figure 8: Quadrupole

they all try to repel each other. If this division happened, the particles would gradually drift apart and be lost. So finally there would not be a beam, there would be just accelerated particles.

Just after the quadrupole magnets runs the trim quadrupoles. Those can be programmed to make up for any small differences that there are between the magnets. This difference happens because magnets are not identical to each other, so this difference has to be solved with the trim quadrupoles.

Figure 9: RF

Another important set of components are the six double ferrite-tuned RF cavities which are long copper tubes, around two meters in length and provid a peak accelerating voltage of 140 kV per beam revolution with the electric field that they have inside. The accelerating field and RF frequency are synchronised with the changing magnetic field in the dipoles to maintain a constant proton beam orbit. The beam makes about 10.000 orbits of the synchrotron as it is accelerated, so they eventually end up with an energy corresponding to 84% of the speed of light.

There are two particularly important straights on the synchrotron, one used for injection of the beam into the synchrotron, and one used for the extraction of the beam from the synchrotron.

A very important process is done in the injection area. Here the charge exchange is carried out of particles. H^- particles are accelerated in the Linac, but H^+ particles are accelerated in the synchrotron, so this exchange is done in the injection area. There are two advantages in making this exchange. The first advantage of this charge exchange injection scheme is that a larger number of protons (2.8x1013) can be accumulated in the synchrotron, which would not be possible otherwise. The second one is because the beam that is circulating around the synchrotron is a protons beam, and if the protons were fed into the beam from the Linac, the incoming beam from the Linac would be repelled by the beam already going around. So with the change, the H^+ ions have the opposite charge to H^- ions, and they get attracted into the beam, so it is much easier to build the injection area.

The charge exchange process is made when the H^- beam crosses through a 0.25 µm aluminium oxide foil at 70 MeV. When the particles cross this foil, they lose first of all one electron (H^- become in H) and then they lose the second electron, so they become in H^+ (a normal proton). However, sometimes these charge exchanges do not work at all, and some of the particles cross the foil with the same charge (H^-) or they lose just one electron (H). These unstripped and partially stripped particles create 2 other beams, but these two beams are intercepted by the beam dump, so they do not disturb the main H^+ beam because the stripped beam avoids the dump and circulates in the ring as shown in the figure 10. The foil is mounted in the middle of four dipole magnets which remove un-stripped beam and collapse after injection to limit foil recirculation. The stripping foil is very efficient at stripping electron off H^-, about 97% efficient in fact. That process of using what is called multi-turn charge injection allows building up very big intensities of protons inside the machine.

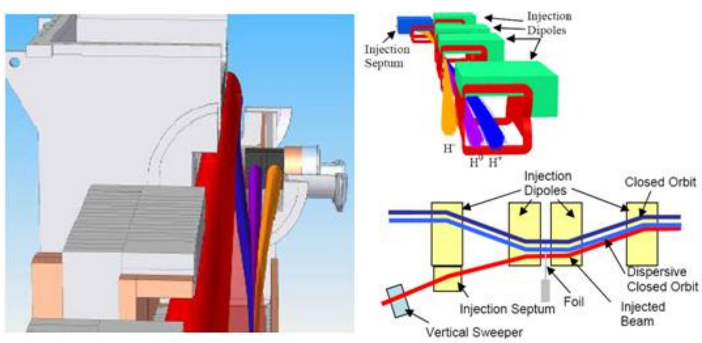


Figure 10: Injection

Further along inside the synchrotron, there is the final area where the extraction of the beam is located. Here, there are more different magnets and they are called “kicker magnets”. They are used to take the beam out of the synchrotron and to put the particles into the extracted proton beam lines.

On the last turn around the synchrotron, the kick magnets provide a kick to the beam. This kick move the beam out of the normal vertical plane that it goes in that keeps it going around the synchrotron, and kicks the beam by just a few degrees, just enough so the beam will go into the next magnet. This magnet is called a septum magnet, and that septum magnet will sweep the beam and put the particles in the extracted proton beam line.

With the addition of the second target station, there are now two extracted proton beam lines. Four out of every five pulses produced in the synchrotron go to the Target Station One, but one out of five goes to Target Station Two.

7.3.3. Target Station 1 (TS1)

The neutron target station has three main parts:

- Target, reflector and moderator assembly in which the neutrons are produced.
- A remote handling cell for maintenance and repair operations.
- A services area containing cooling equipment.

There are eighteen beam channels, nine on each side of the target, which feed the neutron scattering instruments. Neutrons are produced when the 160 kW proton beam from the accelerator hits a metal target. The target is made from a series of thick tungsten plates, (clad with tantalum to prevent the corrosion) housed in a pressure vessel. As the hit produces a huge quantity of energy, the remaining energy has to be removed. This happens because the instruments need other level of energy to work properly, so water cooling channels remove around 90 kW of heat generated in the target.

Four moderators are used to slow down fast neutrons escaping from the target to the lower speeds required for neutron scattering experiments. Two use water at room temperature, one uses liquid methane at 100 K and the fourth consists of liquid hydrogen at 20 K. The different temperatures result in different energy neutrons beams. The moderators are small, about 0.5 litres, and are surrounded by a water-cooled beryllium reflector which scatters neutron back into the moderators and doubles the useful flux of neutrons. A remove handling cell is used to replace a target or moderator and to perform any required maintenance. In operation, all components become highly radioactive, and the purpose-built cell is integrated into the target station. The cell has a pair of manipulators on each side, and operations are viewed through large shielding windows and video cameras.

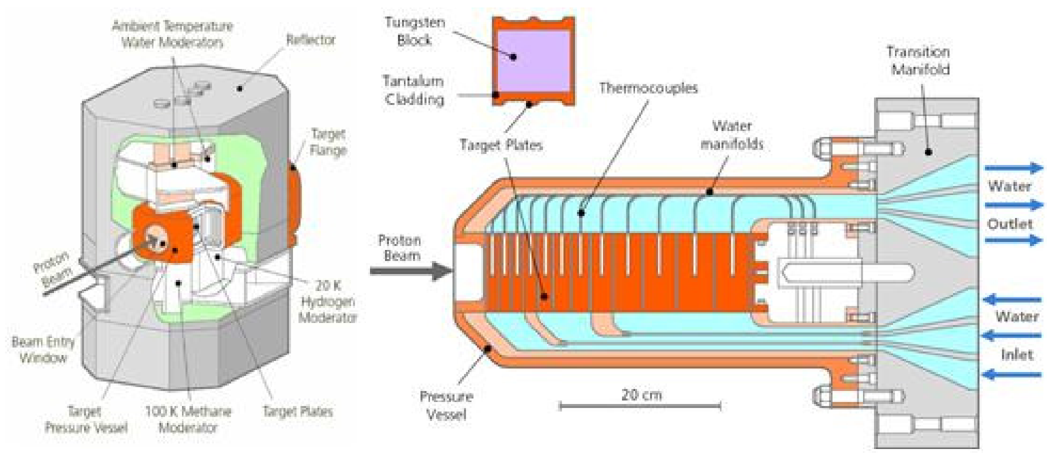


Figure 11: Target assembly and the target.

In the Target Station One there are twenty two different instruments in which the scientists can do their experiments and researches. Each instrument has its own purpose but in general they can be split into four kinds of experiments. These experiments are the following: neutron diffraction, neutron spectroscopy, reflectometry and small angle scattering.

7.3.4. Target Station 2 (TS2)

The Second Target Station is a low-power, low-repetition-rate neutron source optimised to maximise the production of long wavelength neutrons. It is required to produce neutrons of two pulse shape varieties.

The first, a wide pulse shape with full width at half-maximum height (FWHM) no bigger than 300 µs and a modest tail, this is generated by a coupled moderator; whilst the second is a simple pulse shape de-coupled moderator, with little or no tail, and a width comparable to those of the existing ISIS methane and hydrogen moderators (30-50 µs).

These long wavelength neutrons are produced like the neutrons of the TS1. The high energy beam of protons is used to release neutrons from a tungsten target. By scattering these neutrons off sample materials, scientists can visualise the position and motions of atoms. The technique is non-destructive and can be used to study everything from delicate biological specimens to priceless archaeological artefacts. Also other types of experiments are done in the TS2 to make breakthroughs that will underpin the next generation of super-fast computers, data storage, sensors, pharmaceutical and medical applications, material processing, catalysis, biotechnology and clean energy technology.

All this research is carried out in eleven different instruments. All of them can be divided, as in the TS1, into four types of processes.

7.3.5. Muon Target

Muons are produced by colliding the proton beam with a 10 mm thick carbon target 20 m upstream of the neutron target. Collisions produce pions which decay with a mean lifetime of 26 ns into muons. The muon beam is fully polarised, and this polarisation is maintained as the beam is transported to the muon spectrometers. The muon target uses 2-3% of the proton beam.

Muons can be used to study a wide variety of magnetic systems, with the muon acting as a microscopic magnetometer and probing longer fluctuation timescales compared with neutron scattering. Muons are suitable for studies of small-moment, short-range, random, or dilute magnetism. In superconducting material, muons can be used to explore the flux-line lattice generated when a field is applied to a type-II material, complementing small-angle neutron scattering measurements in some cases. Muons can be used to determine fundamental superconducting parameters such as the penetration dept, coherence length, superconducting carrier density and effective mass. They can also be used to study various charge transport phenomena, including ion mobility in battery cathode materials, electron dynamics or charge carrier motion in conducting polymers.

The positive muon can act like a light proton. Where proton or hydrogen atom behaviour is difficult or impossible to study directly, observation of the muon response can enable models of its heavier counterpart to be produced; examples include investigation of hydrogen behaviour in semiconductors. In molecular materials, muons can form radical states sensitive to molecular dynamics, and can be used to study chemical reactions.

The use of the muon technique provides atomic-level information in the following areas: specific examples include studies of organic and inorganic magnetism, modelling hydrogen behaviour in superconductivity (including atomic-level investigations and flux-line lattice studies), and muon technique development including a variety of pulsed environments for muon experiments.

To develops these studies there are five instruments which are used by the scientists.

7.4. ISIS instruments

The instruments are divided in three groups, depending in where they are located. The first area, the biggest and the oldest one, is the TS1. In the TS1 are located twenty two instruments which work with the fastest neutron that are produced in ISIS. The next area, the newest one, is the TS2. In the TS2 are set eleven instruments which work with cold neutrons. And the last area is the Muon target where are placed 5 instruments that works with muons.

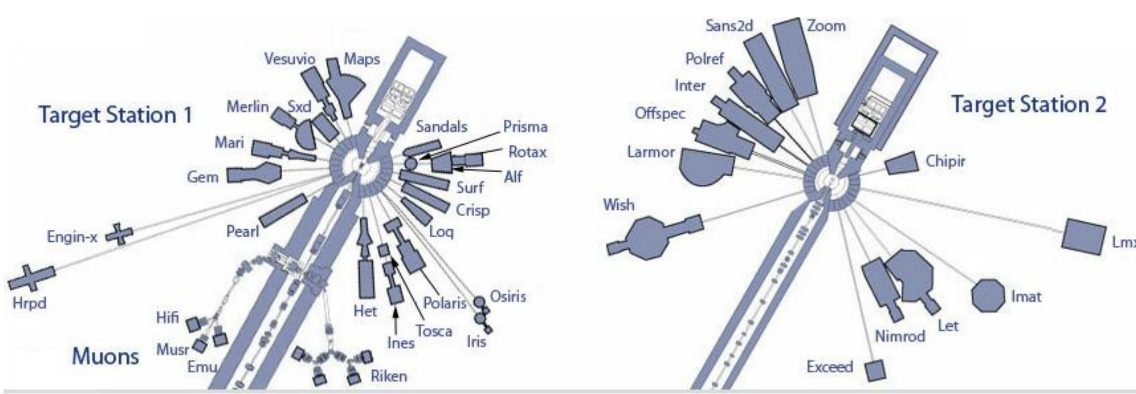


Figure 12: TS1, TS2 and Muon station

All these instruments do many different experiments but at the end all of them work with five distinct techniques: neutron diffraction, neutron spectroscopy, reflectometry, small angle scattering and muon spectroscopy. Depending on these techniques the answer from the experiments are different. Some of them describe the position of the atoms and others describe the movement of the atoms.

7.4.1. Techniques

Neutron diffraction:

Neutron diffraction experiments determine the atomic and/or magnetic structure of a material. This technique can be applied to study crystalline solids, gasses, liquids or amorphous materials.

Neutron diffraction is a form of elastic scattering where the neutrons exiting the experiment have more or less the same energy as the incident neutrons. The technique is similar to X-ray diffraction but the different type of radiation gives complementary information. A sample to be examined is placed in a beam of thermal or cold neutrons and the intensity pattern around the sample gives information of the structure of the material.

- Nuclear scattering:

Neutrons interact with matter differently than x-ray. X-rays interact primarily with the electron cloud surrounding each atom. The contribution to the diffracted X-ray intensity is therefore larger for atoms with a large atomic number (Z) than it is for atoms with a small Z. On the other hand, neutrons interact directly with the nucleus of the atom, and the contribution to the diffracted intensity is different for each isotope; for example, regular hydrogen and deuterium contribute differently. It is often the case that light (low Z) atoms contribute strongly to the diffracted intensity even in the presence of lager Z atoms. The scattering length varies from isotope to isotope rather linearly with the atomic number. An element like Vanadium is a strong scattered of X-rays, but its nuclei hardly scatter neutrons, which is why it often used as a container material. Non-magnetic neutron diffraction is directly sensitive to the positions of the nuclei of the atoms.

A major difference with X-rays is that the scattering is mostly due to the tiny nuclei of the atoms. That means that there is no need for an atomic form factor to describe the shape of the electron cloud of the atom and the scattering power of an atom does not fall off with the scattering angle as it does for X-ray. Diffractograms therefore can show strong well defined diffraction peaks even at high angles, particularly if the experiment is done at low temperatures. Many neutron sources are equipped with liquid helium cooling systems that allow collecting data at temperatures down to 4.2 K. The superb high angle (i.e. high resolution) information means that the data can give very precise values for the atomic positions in the structure. On the other hand, Fourier maps (and to a lesser extent difference Fourier maps) derived from neutron data suffer from series termination errors, sometimes so much that the results are meaningless.

- Magnetic scattering:

Although neutrons are uncharged, they carry a spin, and therefore interact with magnetic moments, including those arising from the electron clouds around an atom. Neutron diffraction can therefore reveal the microscopic magnetic structure of a material.

Magnetic scattering does require an atomic form factor as it is caused by the much larger electron cloud around the tiny nucleus. The intensity of the magnetic contribution to the diffraction peaks will therefore dwindle towards higher angles.

Neutron spectroscopy:

Neutron spectroscopy measures the atomic and magnetic motions of atoms.

Inelastic neutron scattering measures the change in the energy of the neutron as it scatters from a sample. This can be used to probe a wide variety of different physical phenomenon: diffusional or hopping motions of atoms, the rotational modes of molecules, sound modes and molecular vibrations, recoil in quantum fluids, magnetic and quantum excitations or even electronic transitions.

Often knowing the atomic structure of a material will be sufficient to understand its nature. But to gain a deeper insight into the underlying physics of say a phase change, it is necessary to also understand the atomic dynamics. The vibrational motion of atoms is, entirely or in part, responsible for a large number of the characteristic properties of a material, such as the specific heat, thermal conductivity, optional and dielectric properties and electrical resistance, but it is also a direct way of understanding the nature of atomic bonding. And with the current interest in smart or functional materials whose properties are often determined by a complex balance or strong coupling between competing phenomena, understanding the atomic and magnetic dynamics is essential.

The most commonly used spectroscopies are the light scattering techniques: Raman and infrared. Compared to neutron scattering they are cheaper, readily available and highly sensitive. But they do have certain limitations: they can only measure near the Brillouin zone centre and are only sensitive to certain vibrational modes. The calculation of the scattered intensity is also difficult and prone to error and so information is usually only taken from the positions of the observed modes. However, the simplicity and sensitivity of the techniques means that they are often used to identify or “finger print” compounds something that is rarely done with neutrons. Inelastic neutron scattering is usually used to understand the physics of a system. It is highly quantitative probe whose results are directly comparable to numerical and analytical calculation. It can be used to understand the nature of a phase transitions or linked directly to thermodynamics quantities, like specific heat or thermal conductivity, or structural properties such as force tensors or bulk and shear moduli. It is still one of the few methods available to measure phonon and magnon dispersion curves. And, due to the unique nature in way that hydrogen scatters neutrons, it is a natural technique for measuring the vibration of diffusion of hydrogen in a material.

Reflectometry:

Neutron reflectometry is a technique for measuring the structure of thin films. It has applications from materials science through to soft matter and bioscience.

The technique provides valuable information over a wide variety of scientific and technological applications including chemical aggregation, polymer and surfactant adsorption, structure of thin film magnetic system, biological membranes, etc.

The technique involves shining a highly collimated beam of neutrons onto an extremely flat surface and measuring the intensity of reflected radiation as a function of angle or neutron wavelength. The exact shape of the reflectivity profile provides detailed information about the structure of the surface, including the thickness, density, and roughness of any thin films layered on the substrate.

Neutron reflectometry is a specular reflection technique, where the angle of the incident beam is equal to the angle of the reflected beam. The reflection is usually described in terms of a momentum transfer vector, denoted q_z, which describes the change in momentum of a neutron after reflecting from the material. Conventionally the z direction is defined to be the film normal direction, and for specular reflection, the scattering vector has only a z-component. A typical neutron reflectometry plot displays the reflected intensity (relative to the incident beam) as a function of the scattering vector:

$$q_z = 4\pi\lambda.\sin(\theta)$$

Where λ is the neutron wavelength and θ is the angle of incidence. The Abeles matrix formalism or the Parratt recursion can be used to describe the specular signal arising from the interface.

The wavelengths of the neutrons used for reflectivity are typically on the order of 0.2 to 1 nm (2 to 10 Å). Like all neutron scattering techniques, neutron reflectometry is sensitive to contrast arising from different nuclei (as compared to electron density, which is measured in x-ray scattering). This allows the technique to differentiate between various isotopes of elements. Neutron reflectometry measures the neutron scattering length density (SLD) and can be used to accurately calculate material density if the atomic composition is known.

Small angle scattering:

Small angle neutron scattering is a neutron technique able to probe structures at length scales from around 1 nm to more 100 nm. It has a wide of applications from studies of polymers and biological molecules to nanoparticles to microemulsions and liposomes used for cosmetics and drug delivery.

Small angle scattering (SAS) is the collective name given to the techniques of small angle neutron (SANS), X-ray (SAXS) and light (SALS, or just LS) scattering. In each of these techniques radiation is elastically scattered by a sample and the resulting scattering pattern is analysed to provide information about the size, shape and orientation of some component of the sample.

The type of sample that can be studied by SAS, the sample environment that can be applied, the actual length scales that can be probed and the information that can ultimately be obtained, all depend on the nature of the radiation employed. For example, LS cannot be used to study optical opaque samples and SAXS cannot (easily) be employed to study thick samples or samples requiring complex containers, whilst SANS (and SAXS) probe quite different length scales to LS. Thus to a large extent these techniques are complementary. They do, however, also share several similarities. Perhaps the most important of these is the fact that, with minor adjustments to account for the different types of radiation, the same basic equations and “laws” (for example, those due to Guinier, Zimm, Kratky and Porod) can be used to analyse data from any of the three techniques. This is a tremendous advantage and one that has certainly eased the transition from one technique to another for thousands of students over the years.

Muon spectroscopy:

Muons provide a complementary probe to neutrons, particularly in the areas of magnetism, superconductivity and charge transport.

Muons can also be thought of as light protons, and studies of their behaviour can shed light on hydrogen behaviour in technologically relevant semiconductors.

This muon facility is unique in Europe, and one of only four muon facilities world-wide available for condensed matter and molecular studies.

Muons are produced by the proton beam hitting a thin carbon target 20 m upstream of the neutron target. The muons are then fed to seven experimental areas – three in what is called the ISIS European Muon Facility and four in the Japanese-run RIKEN-RAL Muon Facility.

7.4.2. The instruments deeper

Target Station One:

MAPS

Its huge array of position sensitive detectors has created a survey technique that is able to map vast areas of the Brillouin zone, making it possible to see the unexpected. It is able to reveal broad features which could easily be dismissed as background on a triple-axis machine.

The position sensitive detectors give near-continuous coverage over a large solid angle detector array in the forward direction. The pixel size in reciprocal space is significantly smaller than the resolution volume defined by the other instrumental contributions. In contrast, conventional detectors on Het and Mari integrate along one direction in reciprocal space, which overwhelms the intrinsic resolution in that direction. With Maps, there is complete freedom to construct scans along any direction in reciprocal space and project data onto any plane in reciprocal space.

Maps is optimised to measure high energy magnetic excitations in single crystals with varying energy resolution depending on choice of monochromating chopper

VESUVIO

Vesuvio is a unique neutron spectrometer, which uses the high intensity of neutrons in the eV energy range and the pulsed nature of the ISIS source to measure atomic momentum distributions in a variety of condensed matter systems.

Energy transfers in the 1-100 eV region and wavevector transfers between 30 and 200 Å-1 are achieved using a filter difference technique. The energy of the scattered neutron is fixed by a nuclear resonance absorption foil and the incident energy and hence energy and momentum transfers are determined using standard time of flight techniques.

SXD

SXD, the Single Crystal Diffractometer, uses the time-of-flight Laue technique to access large 3-D volumes of reciprocal space in a single measurement.

This makes SXD especially powerful in applications involving surveys of reciprocal space, such as phase transitions and incommensurate structures, and also in applications where sample orientation may be restricted.

Applications of SXD include:

- Structure determination (including Hydrogen atom location)
- Diffuse scattering (thermally induced disorder, disorder resulting from defect impurities, or the structure of short range magnetically ordered systems)
- Phase transitions (including changes of symmetry, and superlattice reflections)
- Incommensurate structures
- Fibre diffraction

MERLIN

Merlin is a high count rate, medium energy resolution, direct geometry chopper spectrometer.

It has a very large solid angle of detectors about eight times that of Het or Mari, with a range of nearly 180° in the horizontal plane and ±30° in the vertical plane. Position sensitive detectors make it ideal for studies of single crystals.

OSIRIS

OSIRIS is a spectrometer optimised for very low energy studies and long wavelength diffraction. These studies can provide information on relatively slow motions in materials such as diffusion in liquids and the movement of protons in batteries.

OSIRIS can be used as either a high-resolution, long-wavelength diffractometer or for high-resolution quasi/ inelastic neutron scattering spectroscopy. For the purpose of description, OSIRIS may be considered as consisting of two coupled spectrometer components.

INES

INES is a general purpose diffractometer and is mainly devoted to materials characterisation (structure refinement and phase analysis), cultural heritage studies and equipment tests.

MARI

Mari is a chopper spectrometer with continuous detector bank coverage ranging from 3° to 134° degrees.

Mari is a uniquely versatile instrument and has contributed seminal work in fields such as quantum-fluids, the dynamics of disordered materials and low-dimensional magnetism. It is also used for studies of biological and polymeric materials, catalysts, thermo-electric materials, geological samples, high-temperature superconductors and liquid dynamics.

GEM

The General Materials Diffractometer is a new generation neutron diffractometer recently constructed at the ISIS pulsed neutron source. GEM can be used to perform high intensity, high resolution experiments to study the structure of disordered materials and crystalline powders.

ENGIN-X

ENGIN-X is a dedicated engineering science facility at ISIS. The beamline is optimized for the measurement of strain, and thus stress, deep within a crystalline material, using the atomic lattice planes as an atomic “strain gauge”. Internal and residual stresses in materials have a considerable effect on material properties, including fatigue resistance, fracture toughness and strength.

ENGIN-X is a 50 m flight path instrument, sitting outside the main ISIS hall. It sits on a curved “supermirror” neutron guide, with a large detector complement centred at 90º 2q. It incorporates accurate and large capacity positioning equipment, and a range of sample environment equipment for engineering studies of materials. ENGIN-X also incorporate considerable improvements in user interface software to simplify the experimental procedure for novice users.

HRPD

HRPD, the High Resolution Powder Diffractometer, is the highest resolution neutron powder diffractometer of its type in the world.

Situated almost 100 m from the ISIS target at the end of a neutron guide, its unprecedented resolution in the main backscattering detector bank, with a Dd/d resolution of $\sim 4 \times 10^{-4}$ which is effectively constant over the wide *d*-spacing range available, gives it unique power in the study of subtle structural details, for example in phase transitions. The ability to separate peaks resulting from small unit cell changes and to allow peaks at shorter *d*-spacings to be resolved from complex materials, where short wavelength epithermal neutrons from the ISIS target allow *d*-spacings below 0.3 Å to be recorded, has enabled HRPD to expand the technique of powder diffraction in novel directions.

IRIS

High resolution quasi-elastic and inelastic neutron scattering spectrometer with long d-spacing diffraction capabilities

IRIS is a time-of-flight inverted-geometry crystal analyser spectrometer designed for quasi-elastic and low-energy high resolution inelastic spectroscopy.

Neutrons scattered from the sample are energy-analysed by means of Bragg reflection from one of two large single crystal arrays (pyrolytic graphite and muscovite mica) in close to backscattering geometry. Each analyser is associated with its own bank of 51 ZnS scintillator detectors. The two analyser banks, which can operate simultaneously, afford high resolution over wide energy and momentum transfer ranges.

HET

Investigations on Het have broadened from studies of high energy magnetic excitations and the dynamics of hydrogen metal systems into the fields of quantum magnetism and non-Fermi liquids.

Het is optimised to measure high energy magnetic excitations. Although originally optimised for magnetic studies with most of its detectors positioned at angles below 30°, it is also used for investigations of dynamics in many other materials including disordered and biological systems. It has produced a large number of important results from powders, amorphous materials and single crystals.

This instrument nowadays is decommissioned.

PEARL

Pearl has been specifically designed for *in situ* studies of materials at high pressure. The application of high pressure can induce dramatic changes in the physical properties of materials. For example, upon applying a relatively modest pressure water transforms to a crystal structure that does not melt until 100℃.

The Pearl High Pressure Facility is a medium resolution high-flux diffractometer optimised for data collection from the Paris-Edinburgh pressure cell.

SANDALS

SANDALS is a diffractometer especially built for investigating the structure of liquids and amorphous materials.

Using SANDALS it is possible to measure the static structure factor, S(Q), of a disordered material over a wide range (0.2-50 Å-1) of momentum transfers.

SANDALS experiments usually employ the powerful technique of isotopic substitution technique to perform in depth structural studies on the atomic scale.

The combination of an intense pulsed neutron source and a large number of detectors at low angles make SANDALS particularly useful for measuring structure factors containing light atoms such as hydrogen and deuterium.

PRISMA

Prisma is an inverse geometry crystal-analyser spectrometer and high resolution diffractometer designed to measure excitations, critical scattering and diffuse scattering in single crystal samples.

In diffraction mode it can be used for reciprocal space surveys with large Q coverage and good signal noise, and is particularly well suited for magnetism due to the large flux of long wavelength neutrons delivered by the supermirror guide system in the primary spectrometer. In inelastic mode, data can be collected along a single Q-w line in reciprocal space parallel to ki (Prisma scan) or individual analysers can be set up to measure several different Q-w lines parallel to ki The inelastic and diffraction modules are located on opposite sides of the incoming neutron beam, enabling experiment modes to be changed without disturbing sample environment equipment.

ROTAX

ROTAX houses the ALF crystal alignment facility, and is used for characterisation of samples destined for other ISIS beamlines. ROTAX is used for detector and equipment tests.

POLARIS

Polaris is the ideal complement to high resolution powder diffractometer HRPD. Its strengths lie in the rapid characterisation of structures, the study of small amounts of materials, the collection of data sets in rapid time and the studies of materials under non-ambient conditions.

The Polaris instrument at ISIS is a high intensity, medium resolution powder diffractometer. It is optimised for the rapid characterisation of structures, the study of small amount of materials (as little as ~1mm3), the collection of data sets in rapid time (with data collection times down to ~5 minutes) and the study of materials under non-ambient conditions, where the ability of time-of-flight powder diffraction to collect an entire diffraction pattern at a single, fixed scattering angle is a very powerful attribute. In particular, detector banks allow studies of samples within complex sample environment equipment, such as high pressure cells or reaction vessels.

ALF

ALF provides quick, intuitive, rapid access for the alignment and assessment of single crystals for users of the main ISIS excitation instruments and the WISH diffractometer.

The ALF crystal alignment facility has a goniometer stack and a bank of position sensitive detectors which can be used to check the quality of single crystals, or align single crystals or multi-crystal arrays in preparation for other experiments at ISIS.

SURF

Surf is one of the leading instruments in the world for liquid interface research.

Surf is the newer of the two Neutron Reflectometers (NR) at ISIS. Compared to its sister instrument CRISP, SURF is optimised for higher flux. With horizontal sample geometry it is therefore ideally suited for the study of liquid surfaces.

CRISP

Crisp is one of five neutron reflectometers (NR) at ISIS. It is the original NR instrument and was designed for high resolution studies of a wide range of interfacial phenomena.

The instrument is highly automated, allowing reproducible measurements to be made with high precision, and the sample geometry is horizontal to facilitate the study of liquid surfaces. There is also overhead crane access for the installation of large items of sample environment. Please see the sample environment page for the list of available sample environments.

LOQ

LOQ is a relatively simple instrument, consisting of an 11-metre evacuated beamline down which neutrons fly towards the sample. After being scattered by the sample, they hit a fixed two-dimensional detector 4 metres away, which can detect the positions and times of arrival of the neutrons. The resulting pattern is analysed to provide information on the nanostructure of the sample.

LOQ may be used to investigate the shape and size of large molecules, small particles or porous materials with dimensions in the range of 1 - 100nm. Length scales of up to 400nm can be probed in highly anisotropic systems. This instrument should therefore be of interest to anyone involved in the study of colloids, nanoparticles, polymers, bio-molecules, alloys, composites or porous systems.

TOSCA

Tosca is an indirect geometry spectrometer optimised for the study of molecular vibrations in the solid state.

Tosca's simple operation and the similarity of the spectra to the optical analogues of infrared and Raman spectroscopy make it one of the most approachable instruments for first-time users. Science on Tosca includes studies of catalysts, hydrogen storage materials, hydrogen bonded systems, advanced materials, biological samples and organic compounds such as drugs.

<u>Target Station Two:</u>

ZOOM

This instrument is under construction.

Zoom will be a flexible, high count rate small-angle scattering instrument. It will use novel focussing devices and high resolution detectors to reach very small Q (VSANS).

Zoom will be a flexible, high count rate small-angle scattering instrument for advanced materials, magnetism, environment science, pharmacy and healthcare to study length scales 2-2000 nm. For the first time at ISIS, it will offer polarised small angle neutron scattering and will use novel focusing devices and high-resolution detectors to reach smaller Q, to complement the Sans2d instrument, without building a very long beam line. Zoom will start commissioning experiments in February 2015.

SANS2D

Sans2d is a Time-of-flight Small-Angle Neutron Scattering instrument.

Sans2d can be used to examine size, shape, internal structure and spatial arrangement in nanomaterials, 'soft matter', and colloidal systems, including those of biological origin, on length scales of between* 0.25-300 nm. SANS does not locate individual atoms but rather looks at the larger structures they form. This gives important insights into many everyday materials and biological systems.

POLREF

Polref is a polarised neutron reflectometer designed for the study of the magnetic ordering in and between the layers and surfaces of thin film materials.

It is now routinely possible to grow artificial structures comprising many layers of different atoms (multilayers) with almost atomic-plane precision and distinct physical properties. The revolutionary development has been the exploitation of the magnetism of electrons (called spin) rather than the charge.

Through precise control of the neutron spin, unique information on the size and direction of the magnetism as a function of depth can be obtained, allowing very complicated structures to be studied layer by layer.

INTER

High-intensity chemical interfaces reflectometer offering a unique facility for the study of a range of air/liquid, liquid/liquid, air/solid, and liquid/solid interfaces.

In neutron reflectivity experiments, a narrow beam of neutrons is bounced off a surface. Like beams of light bouncing off a mirror, neutron beams bounce off surfaces at the same angle as they arrive, and are collected by neutron detectors. Inter enables the use of smaller samples and expands the time scales that are observable for dynamic studies, encouraging the investigation of systems more closely aligned with those found in nature and industry.

OFFSPEC

Offspec is an advanced reflectometer giving access to nanometre length scales parallel and perpendicular to interfaces. It uses the technique of neutron spin-echo to encode the path that neutrons take through the instrument.

Measurements of specular reflectivity give information about structure perpendicular to a surface interface, but an increasing number of important science and technology issues in the study of thin films, multilayers and interfaces concern structure in the plane of the interface

LARMOR

This instrument is under construction.

Larmor is a multi-purpose instrument for SANS, diffraction and spectroscopy utilising the larmor precession of polarised neutrons. Larmor will provide a suite of techniques not currently possible at ISIS and will also expand the range of spatial and temporal length scales to new areas.

The Larmor instrument will implement a number of sophisticated and recently developed techniques based on the application and extension of the neutron spin-echo concept in a single instrument. This multi-purpose instrument for SANS, diffraction and spectroscopy relies on the Larmor precession of polarised neutrons and will be able to measure changes in materials ranging from 0.1 femtometres up to 20mm.

WISH

Wish is a long-wavelength diffractometer primarily designed for powder diffraction at long d-spacing in magnetic and large unit cell systems, with the option of enabling single-crystal and polarised beam experiments.

In complex systems, the magnetic structure has a large number of degrees of freedom (typically the three components of the magnetic moment on several inequivalent atoms), and the *d*-spacing range available to observe Bragg peaks is limited due to fall-off of the magnetic form factor.

High-resolution cold-neutron powder diffraction excels when multiple nearly overlapping Bragg peaks occur at long *d*-spacing. In this case, sheer flux is not sufficient to extract all the available information, and much better results can be obtained with a high-resolution diffractometer such as Wish, even at the cost of losing some flux.

CHIPIR

Chipir will be an instrument for rapid testing of effects of high energy neutrons, which nowadays is under construction.

The interaction of cosmic rays with the earth's atmosphere generates showers of particles including high energy neutrons. Cosmic neutron radiation can disrupt the normal operation of electronic systems, particularly in aircraft and road vehicles with problems ranging from wiping a device's memory to damaging the electronics. At normal aircraft flying altitudes of 30,000 to 35,000 feet, these neutron showers are intense enough to disrupt aircraft electronics through 'single event effects' (SEE) and good design and testing of the electronics is necessary to compensate for SEE disruption. As the dimensions of electronic chip components have shrunk below 100nm, neutron SEE testing is moving outside the traditional aerospace sector into other areas such as transport, communications, medicine, and computing systems.

Chipir will be the first dedicated facility outside of the US to look at how silicon microchips respond to cosmic neutron radiation. The new neutron beam line at ISIS will dramatically speed up electronics testing with a measurement of just one hour being equivalent to exposing microchips to high-energy neutrons over hundreds of years of flying time in an aircraft. The instrument will be the world's best facility for screening microchips with neutrons, leading to safer, more reliable electronic systems.

IMAT

Imat will be a neutron imaging and diffraction instrument for materials science, materials processing and engineering, which nowadays is under construction.

The special features of the instrument will be energy-selective neutron imaging and the combination of neutron imaging and neutron diffraction. It is expected that Imat will start operating in March 2015.

Imat will offer a combination of imaging and spatially resolved diffraction modes such as neutron radiography, neutron tomography, energy-selective imaging, neutron strain scanning, crystallographic structure and phase analysis, texture analysis, and non-destructive testing.

LET

Let is a cold neutron multi-chopper spectrometer for the study of dynamics in condensed matter to understand the microscopic origin of material properties.

The study of dynamics in condensed matter with inelastic neutron scattering provides one of the most exacting tests of the understanding of the microscopic origin of the material properties, particularly when combined with powerful computer modelling techniques now being pioneered.

The ability to make quasi-elastic and inelastic measurements over a wide dynamic range from 0.5-80 meV on a single spectrometer is quite unique. Combined with position sensitive detectors covering scattering angles from 3° to 140°, Let will have a considerable impact in many disciplines including bio-materials, polymers, magnetism, geo-science and quantum fluids.

NIMROD

Nimrod is a near and intermediate range order diffractometer designed to provide continuous access to length scales ranging from the interatomic (<1 Å) through to the mesoscopic (>300 Å).

Nimrod bridges the traditional gap between SANS and wide-angle neutron scattering, by using a common calibration procedure for all Q-scales. The instrument makes full use of the longer wavelengths on the second target station, to increase the upper limit of the accessible correlation length, while also extracting high-resolution from the shorter wavelengths.

LMX

Lmx will be an innovative single crystal neutron diffractometer that will provide a high flux cold neutron solution for problems in large molecule chemical and biological structure. This instrument currently a proposal.

The instrument will be a world-leading single crystal diffractometer, ideally suited to the ISIS second target station, and will access the large structures that play a crucial role at the forefront of modern molecule-based materials and molecular biology. Lmx will contribute substantially to two of the second target station's science themes, namely advanced materials and biomolecular sciences, with a significant but smaller contribution in the third area of soft condensed matter.

Lmx provides an outstanding opportunity for tackling some of the exciting and leading edge areas in chemistry and structural biology which are currently not within the scope of existing ISIS instrumentation and not yet well catered for at neutron facilities internationally.

EXCEED

Exeed will be, because is still a proposal, a neutron time-of-flight diffractometer optimised for extreme environment studies of materials which will complement the capabilities of Wish on TS2 and Pearl on TS1. Exeed will deliver an extremely bright, focused beam in the thermal-cold region, providing world-class access to regions of the phase diagram that have so far eluded neutron studies. This instrument will provide facility users with access to:

- High pressures (above 50 GPa using diamond anvil cells)
- Combinations of extreme environments: very low temperatures (mK) or very high temperatures (2000 K) with high pressure (including laser heating in cells with transparent gem anvils) and high pressures in high magnetic fields (up to 10 Tesla).
- High temperatures and liquid state studies (up to>3000 K) in levitation environments

Muon Target:

EMU

EMU is a 96-detector µSR spectrometer which is optimised for zero field and longitudinal field measurements. Fields of up to 4500 G can be applied (this can be extended to 5000G if required), and sample temperatures in the range of 50mK to 1500K can be produced using a variety of sample environment equipment.

MUSR

The MuSR spectrometer is a general purpose instrument. However, the emphasis of the experimental work conducted is investigating magnetism and superconductivity.

MuSR is a 64-detector µSR spectrometer which can be rotated through 90o to enable both longitudinal and transverse measurements to be made. Fields of up to 2500 G can be applied, and sample temperatures in the range of 40 mK to 1000 K can be produced using a variety of sample environment equipment.

HIFI

The high-field muon instrument at ISIS, called HiFi, provides applied longitudinal fields up to 5 T.

The magnet is a 5 T superconducting split-pair, with high field homogeneity over the sample volume and actively compensated stray field. It has additional z-axis coils up to 400 G for small changes to the main field (for example, for sweeping through level crossing resonances) as well as 150 G x- and y-axis transverse coils for calibration measurements, etc.

ARGUS

Argus is a muon spectrometer for condensed matter and molecular studies.

The RIKEN - RAL Muon Facility is an international collaboration with the RIKEN institute in Japan to promote muon science. It supports a wide range of investigations including muon catalysed fusion studies and fundamental muon investigations.

The muon instrument Argus (**A**dvanced**R**iken **G**eneral-purpose m**U**sr **S**pectrometer) is housed in Port 2 of the RIKEN-RAL Muon Facility. It can be used for a wide variety of studies in the areas of magnetism, superconductivity, charge transport, molecular and polymeric materials and semiconductors.

8. Cooling system

The cooling system of ISIS is essential in the facility due to the nuclear reaction produced inside both target stations. As a consequence, the energy has to be moderated by the cooling system. Apart from these two targets, the instruments used around the facility also need a cooling system, as a result of the high energy that they need to be able to run their tasks.

This system was built many years ago, so it has been being modified since those years to keep the system in good condition. For this reason the documentation and drawings of the circuits have to be updated every year. More than one circuit has been changed during the last few years, and there was a needed to update these circuits to maintain developing the facility.

The temperature control of the facilities is done through different types of cooling systems. The main system is the tower water (TW) which supplies water to the others circuits to be cooled. The others circuits are the followings: the air conditioning, the chilled water (CW), the demineralised water (DM) and the high purity demineralised water (HP). There are also others that work independently, like hydrogen and methane moderator cooling systems.

8.1. General description

There are five different areas composing the cooling system. These areas are: the Linac, the Synchrotron, the TS1, the TS2 and the group of buildings where the cooling system starts (R11, R10 and R4).

The process starts by filling the cooling towers with tap water. They are located in the R11 and there are three of them. The three of them are never used at the same time, one of them is always used as a back-up in case of one of the other fails. During this period the cooling tower which is stopped, is cleaned and would be fixed if it was broken.

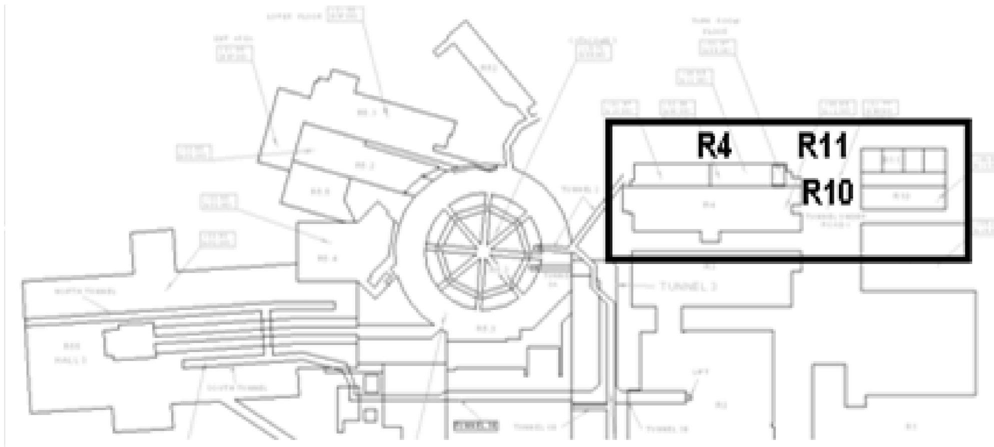


Figure 13: Location of the R4, R11 and R10

When the tower water (TW) is cooled (until room temperature), it goes to the pumps room, which is in R10. In this area there are three pumps connected in parallel pumping the water into the next area, the R4. The softener area is also located in R10. In the UK the tap water normally has a high percent of lime. Consequently, the lime has to be removed to keep the water circuit clean and to preserve the equipment in good conditions for as long as possible.

In the first area of the next building, the R4, three types of water are produced. These are the CW, the DW and the HP. The CW is produced by four chillers connected in parallel. The DW and the HP waters are produced by the demineralisation system that is installed in the building. The three processes use the TW to be able to carry out their duties. As a result, a good maintenance of the TW is required in the facility.

In the second area of the R4 building the air conditioning water for the synchrotron is established. This system also involves three coolers as in the previous area. The cooled water is used to cool the air which is introduced into the synchrotron by two huge pipes. These three coolers are connected in parallel to avoid any problems if one of them fails.

The three different waters (the TW, the CW and the HP) are sent through a tunnel located below the R4 which connects the two areas of the R4 with the synchrotron.

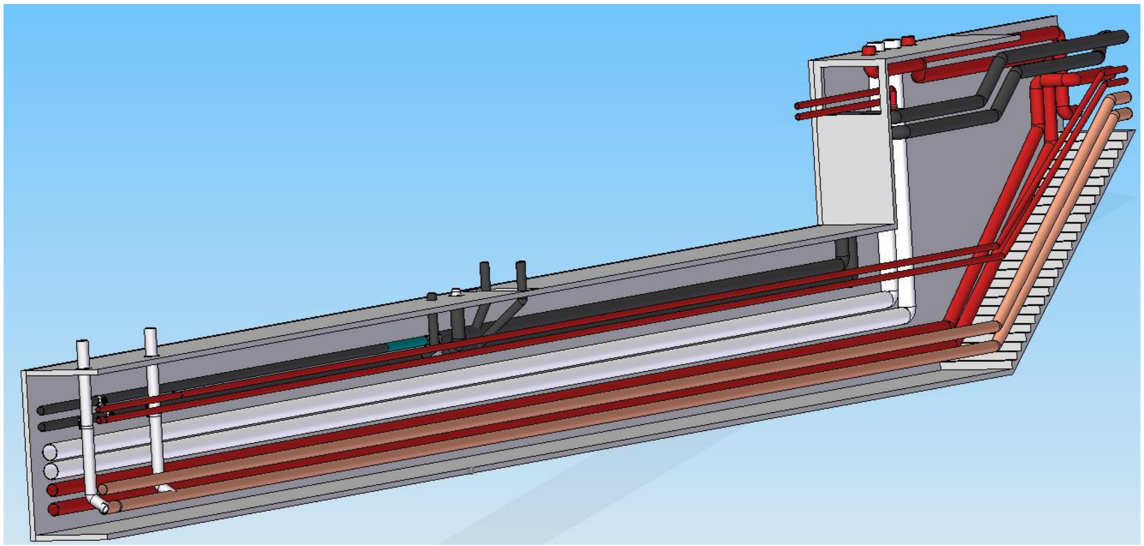


Figure 14: Tunnel 2 (R4)

Here it is divided and sent to the final areas: Linac and TS1.

On the other hand there is the cooling system of the TS2, which is completely independent. The building has its own cooling system with its own cooling towers and chillers. All the processes done in the R11, R10 and in the R4, in this case, are done in the same way in the building of the TS2. Both circuits, the first one located at the R11, R10 and R4 buildings, and the second one, carried out in the TS2, are very similar because the two of them are used to cool down similar facilities or equipment.

To finish with the cooling system, the water from the drainage system has to be collected. The reason to collect this water is because some of the cooling water is in contact with the radiation. As a result, the water becomes radioactive and it has to be treated to remove the radiation. The collected water is sent by pumps to the radioactive water well situated below the synchrotron. When the treatment is finished, the water is transferred to a tank located between the R4 building and the synchrotron. In this tank the water is checked to know the radioactive level and if it is safe, the tank will be emptied. If the radioactive level is high, the water will be relocated again into the well until the water will become safe.

Figure 15: The tank.

8.2. Parts of the circuit

8.2.1. Tower water:

The tower water is the main system. It starts in the three cooling towers (~20MW) situated at the R11 building. Two of the three towers are filled with tap water.

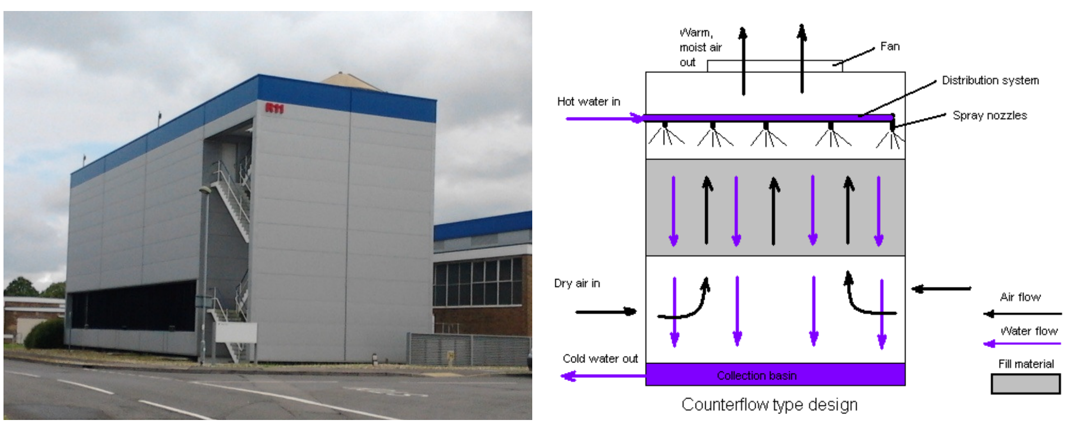


Figure 16: Cooling towers.

The water of the cooling towers is cooled using the dry air from outside, see the diagram. This happens because the walls of the tower are made with grilles, and as the grilles facilitate the draught, the water is cooled. In order to decrease the temperature even more, the water is scattered from the top of the tower like a shower. As a result the water drops are cooled faster.

Another important part of the circuit of the TW, which is at the beginning, is the softener area. This area is in charge of removing the lime directly from the tap water, so it can be used in the cooling towers. This process reduces the total percent of the lime in the TW. Also it is very important as the lime damages all the sensitive instruments and equipment that are around the facility. The use of clean water is essential.

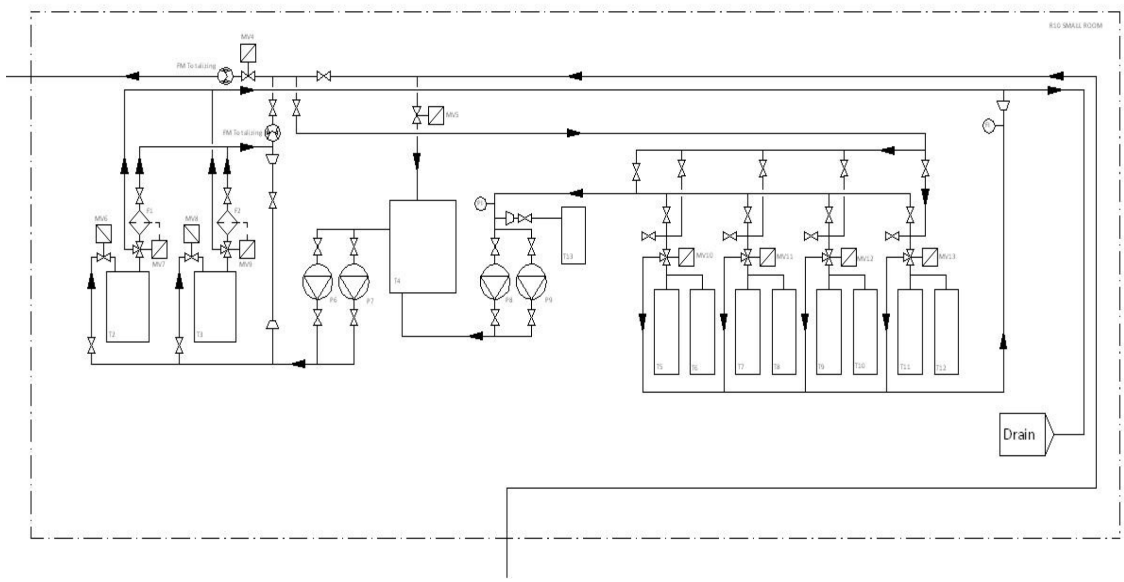


Figure 17: Softener area

The TW is also used in the R4 to produce water for two different subsystems with the help of seven chillers located around the same building. The first four chillers, which are in the east area of the building, produce the CW used to cool the instruments along the facility. However, the other three, situated in the west area, are used to cool the water that later on is used to cool the air conditioning of the synchrotron. The cooled air is pumped into the synchrotron with two massive pipes and they channel the air flow into the synchrotron below the floor.

Once the TW is used to produce the chilled water and the air conditioning water for the synchrotron, it gets hot due to the heat transferences of the chillers, so it needs to be sent back to the cooling towers to get cool again. In this way, the system is ready to restart the circuit.

When the TW crosses the R4, it goes through tunnel 2 towards the synchrotron. There the TW is redirected into three different circuits: one goes to the synchrotron, another one goes to the Linac and the last one goes to the TS1 building.

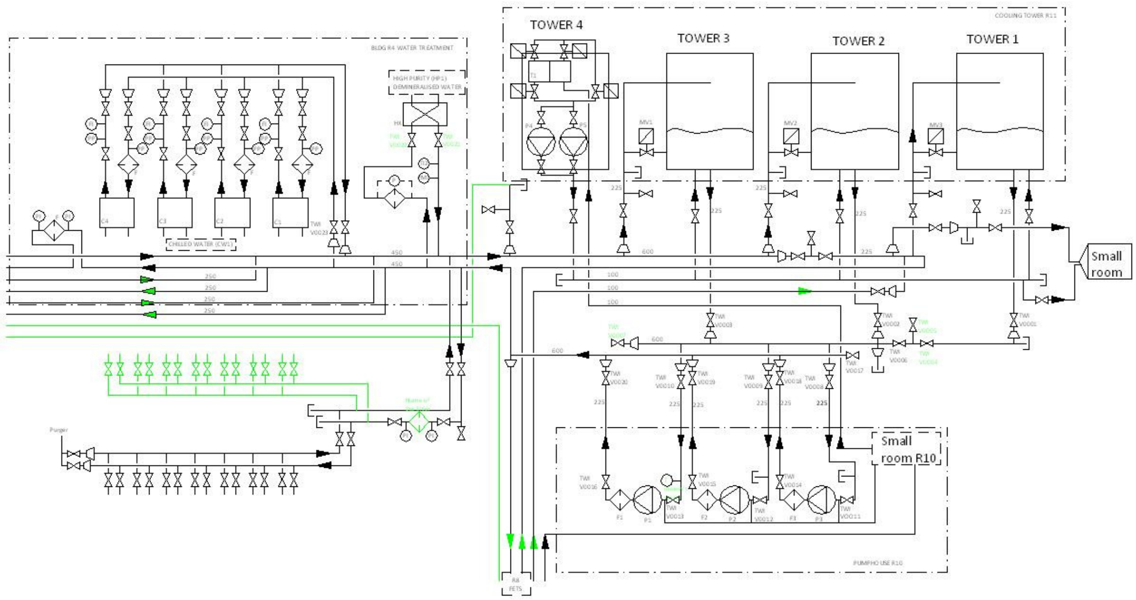


Figure 18: Drawing of the TW circuit from the R4 until the R10

- Synchrotron:

In the synchrotron the TW goes around the ring supplying cool water to the equipment and the instruments. Furthermore, the TW supplies water to the heat exchangers connected with the DW.

- Linac:

The function of the TW in the Linac is to provide water to the ten air handling units that are around the building and also to a few instruments or equipment which need the TW to work property.

- TS1:

In the TS1 the TW circuit is used to provide TW to the instruments which are inside the target station and to some of them outside the target station. Apart of the instruments there are other equipment that also need the TW: the heat exchangers and some apparatus inside the target.

- TS2:

The TS2 is not directly connected with the main circuit as explained before. The building has its own cooling towers, so the TW of the TS2 does not start in the R11, it starts in the R80 (a building of the TS2).

The TW circuit of the TS2 starts with the centralised chemical storage, which is composed of 3 tanks (the inhibitor, the primary biocide and the secondary biocide). When the water is treated, it is sent to the five cooling towers situated in the roof of the R80. This water is used to remove a percentage of the heat of the chilled water.

8.2.2. Chilled water:

The chilled water (CW) is used to cool the water to lower temperatures and also to cool instruments which need a high stability in their temperature. The CW has five different circuits. The longest starts in the R4, and after it is divided in two parts, it finishes in the synchrotron and in the TS1. The TS2 also has a CW circuit, but it is a separate circuit, such as the TW. The next three circuits are smaller than the previous two. One of them is in the Linac, other one in the R4 and as mentioned before it cools the air conditioned. The last one is located in the TS1 and it provides CW to the target.

The first CW circuit is produced by four chillers, which are in the east part of the R4. Each chillier has 354 KW of power and they cool the water from 12℃ to 7℃ . Once the CW is cooled, the water is pumped by two pumps into the tunnel 2 of the R4. When the CW arrives at the end of the tunnel it is divided in two parts: synchrotron and TS1.

- Synchrotron:

The CW in the synchrotron is used for cooling the demineralised water used in the machinery of the synchrotron. The cooling is done with two heat exchangers that transfer the temperature from the chilled water to the demineralised water.

- TS1:

There are several uses of the CW in the TS1. Four of them have to be emphasised, these are the most important uses of the CW circuit in the R55. Two supply CW to two air handling units that are in the H.B.U. and in the middle of the South tunnel. Another one is connected with one of the instruments of the TS1 (MAPS) and the last one supplies CW to the heat exchanger which cools the demineralised water of the Muon facility. The main location of these circuits of the CW in TS1 is in the two tunnels (South tunnel and North tunnel) which are below the target station floor level.

On the other hand, the CW is also used for another use not totally related with the TS1. It is used to provide CW to the building which is next to the R55, the building where the Linac is.

Returning to the five main CW circuits of the facility, the second system is the CW system of the TS2. This system produces two CW circuits in the R80 and these two circuits are produced by five cooling towers and three chillers which are in the fourth level of the building.

The first circuit uses only the cooling system of the cooling towers to cool the CW. This circuit supplies the CW to another two circuits and each circuit has its own heat exchanger. The first heat exchanger cools the water from 45℃ to 35℃ and this water is used to cool the helium (He) compressors. The second heat exchanger cools the water from 27,5℃ to 20℃ and the water is used to cool the target services area, the instruments area and the target services.

In the second circuit, the two cooling systems, the cooling towers and the chillers, are used to cool the CW. In this circuit the water is cooled from 12℃ to 7℃ and it is used in several processes.

Continuing with the five main circuits of the CW, the next one is located in the Linac. The CW arrives into the Linac in two ways. The first one from the TS1 and the other one from the three chillers located outside the R5.1.

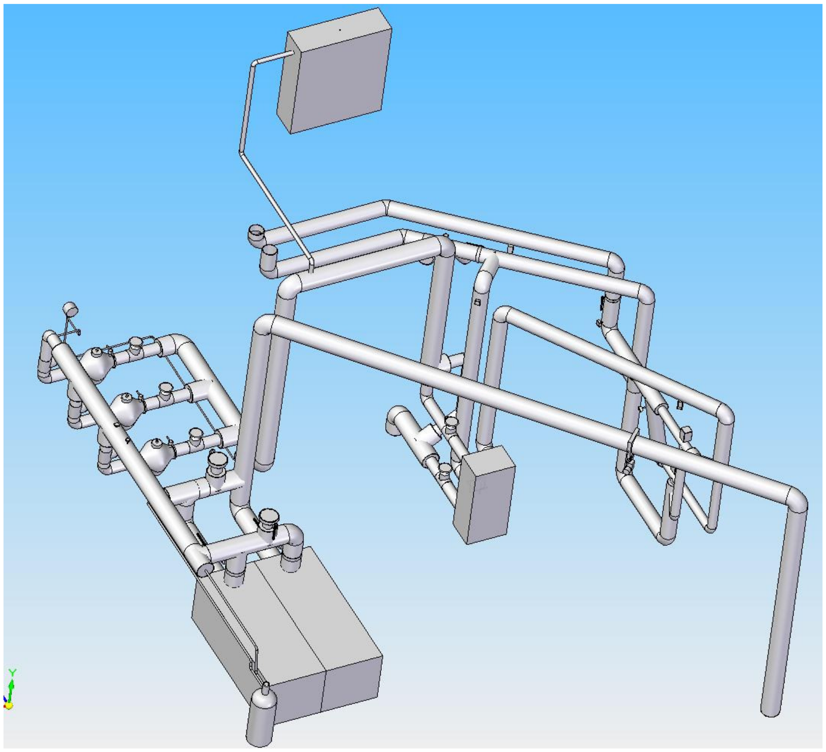


Figure 19: R 5.1

The three chillers are used to cool the demineralised water, which is the R5.1, with a heat exchanger and also to supply CW to one of the air handling unit, which is also in the R5.1.

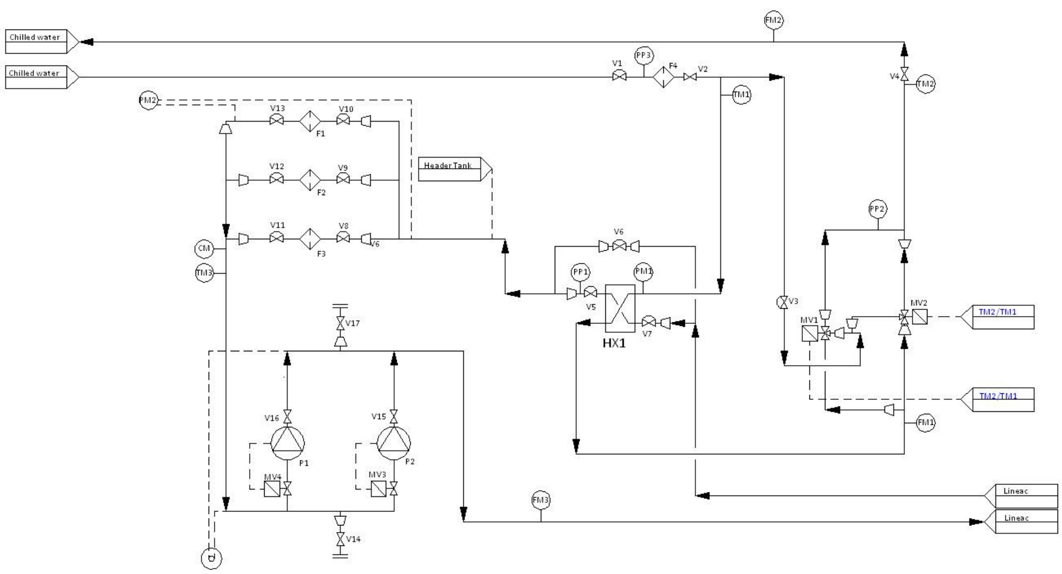


Figure 20: R 5.1 scheme

The circuit arriving from the TS1 is used to supply CW to five air handling units. Three of them are in the R5.5, another one is in the R5.2 and the last one is in the R5.1.

Going back to the five main circuits of the CW, there is another sort of CW circuit in the west side of the R4. This circuit was explained before, however, a deeper description is going to be done.

As mentioned before, the process starts with the three chillers, which are connected in parallel. They have 510 KW of power and they cool the water from 12℃ to 7℃. Once the cooling process is carried out, the pump (there are two pumps, however only one is used in the process) pumps the CW to the two air handling units. In the air handling unit the CW is used to cool the air conditioned which is sent into the synchrotron to cool the facility. When the CW leaves the air handling unit, as it is heated by the temperature transferences, it is sent to the chillers again, closing the process.

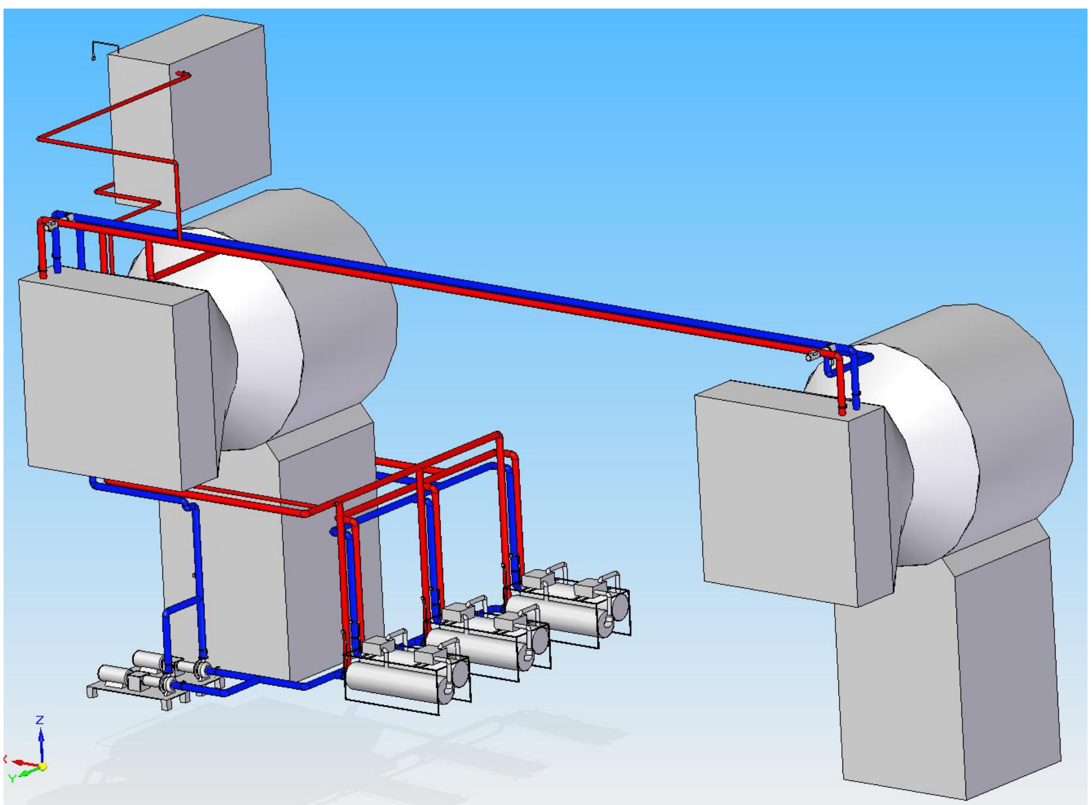


Figure 21: R4 West area

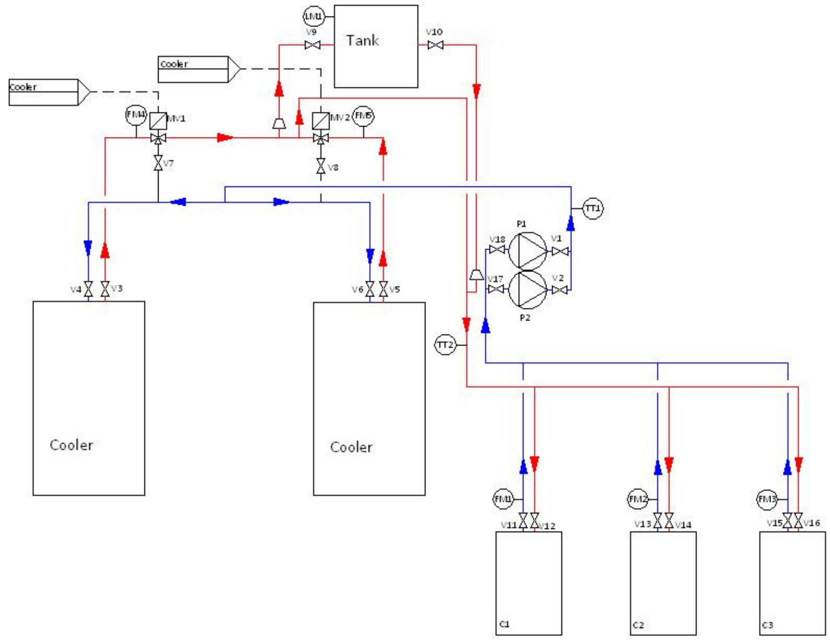


Figure 22: R4 West area circuit.

The last CW circuit is in the TS1. It is located behind the target and it produces CW to supply the target with the water that the equipment needs.

8.2.3. Demineralised water:

The demineralised water (DW) is used to cool the sensitive machineries of the facility and also as an electrical insulator and high purity for higher voltages. This equipment needs water with a little percentage of minerals because their functions might be affected by them.

The system starts with the demineralised make-up (DM1). This is the main and the longest circuit. The DM1 supplies water to the rest of the circuit of demineralised water. It starts in the R4 and finishes in three areas: the Linac, the synchrotron and the TS1.

- DM1:

The DM1 is produced in the east side of the R4, in the water treatment plant. It is divided in three pipes, each of them with a different destination.

The first pipe is pointed towards the Linac. Here, the DM1 is introduced into another circuit that becomes the DW2.

The other two pipes have the same destination, the TS1. However, one of them also provides DM to storage tanks (ST1, ST8, ST9, ST11 and ST12) situated in the synchrotron. From these STs, six circuits are generated: a DW3, a DW4, a DW8, a DW9, a DW10 and a DW12.

When the DM1 arrives to the south tunnel, it is redirected through a link tunnel to the north tunnel. In the north tunnel, the DM1 is separated and it generates another circuit, a DW1. The DM1 is also stored into five STs.

A new circuit starts from the ST18. This circuit is the HP2 and is sent to the R5.4. The other four STs, the ST5, the ST16, the ST17 and the ST19, are used to store the DM.

- DW1

Going back to the DW1 circuit, it provides water to many pieces of equipment and building areas. Before the division, the DW1 is pumped by three pumps located in the R55. Once the water is pumped, it is sent to five areas: the south tunnel, the north tunnel, the synchrotron, the pre-injector and the roof the R55.

In the south tunnel the DW1 is divided into two flow consoles, the flow console 1 and the flow console 2. Afterwards, the DW is sent into the instruments. From the flow console 1, the water is headed towards the muon facility. In the flow console 2, the water is pointed toward different instruments such as: DEVA, MuSR, EMU, SEPA, SEPC, SY1 and SY2.

In the north tunnel there are other four flow consoles. They are numerated from the 3rd to the 6th. The flow console 3 and 4 supply the muon facility. The number 5 provides water to the muon coil and flow console 6 is used to send water to the RIKEN instrument.

In the synchrotron the DW1 circuit is split in twelve panels. From each panel, the apparatus in the synchrotron are provided with the DW.

In the last two areas the water goes to the pre-injector located in the Linac and to the roof, where the water is used to supply the six air blast coolers.

- DW2:

This circuit is generated with the water of the DM1. This water is stored in the ST21 and afterwards it is sent into three filters. It is also cooled with a heat exchanger (HX19) located in the R5.1 that works with the CW. Finally the water is sent into a 70 MeV injector.

- DW3:

The DW3 is located below the synchrotron, in a catacomb. The DW3 uses the water that is stored in the ST1 and this tank is filled by the DM1. The DW3 is used to cool the injection HEDS beam stops and the collectors which are in the synchrotron. To cool the water, the circuit uses a heat exchanger (HX2) that is connected to the TW.

- DW4:

The DW4 is used to cool the extract septum magnet. It is located also in the catacomb of the synchrotron. This circuit uses the water of the ST12 which is filled by the DM1. As the DW3, the DW4 also uses a heat exchanger (HX10) to cool the water using the TW.

- DW7:

This circuit is in the R55. It cools the muon facility using a heat exchanger (HX22) with the CW.

- DW8:

The DW8 is placed in the catacomb and it is used to cool the synchrotron beam dump. The circuits uses the water of the ST11 and a heat exchanger (HX1) ,connected to the TW, to carry out the task.

- DW9:

The DW9 circuit cools the three resonators of the synchrotron. It is set in the catacomb and is filled by the ST9, which uses water from the DM1. To cool the water a heat exchanger (HX18) with CW is used.

- DW10:

The DW10 is similar to the DW9. It also cools three resonators and uses the same technique to cool the circuit. However, it uses the ST8 and a heat exchanger (HX17) connected to the CW system.

- DW11:

The DW11 is located in the RFQ test area (R8). It is used to cool the valve test rig and the RFQ test rig. The circuit operates with the water of the DM1 and with a heat exchanger (HX5) using the TW.

- DW12:

As the DW11, the DW12 is placed in the R8, in the magnet test area. It cools the Rist and the Rist test rig. This circuit obtains the water from the DM1 and it cools the water with a heat exchanger (HX4) using the TW.

8.2.4. High purity demineralised water

High purity (HP) water is used to cool the most sensitive areas in the facility. This water is the highest purity water in the facility, because the water cannot interfere with the particles during the cooling process. There are two circuits of HP, the HP1 and the HP2.

- The HP1:

This circuit starts in a water treatment room placed in the R4. The water comes from the make-up water circuit and it is cooled using two heat exchangers (HX23 and HX24). The water also goes to the regulator room from the R4. In this room the HP1 supplies water to two transistor regulator banks.

Once the HP1 leaves the R4, the circuit is sent to the surrounding area of the synchrotron. Here the HP1 is divided in another three ways. One is sent into the synchrotron, another one into the Linac and the last one through the tunnel 6 to the R6 and R7.

In the Linac the HP1 is used to provide water to four modulators. From these modulators the water is sent to other equipment, such as: the cooker rack, the ignitron, the RF system, the dummy load and several valves.

In the synchrotron, the water is divided and sent into two panels located in the catacombs. From each panel, the HP1 circuit is again split and transferred into three High Power Drive (HPD). To be more specific these HPD are the followings: the HPD NO 7, the HPD NO 8, the HPD NO 9, the HPD NO 2, the HPD NO 3 and the HPD NO 4.

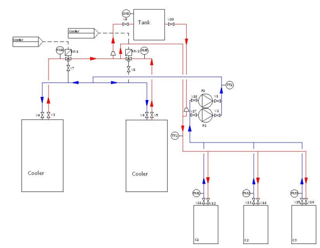
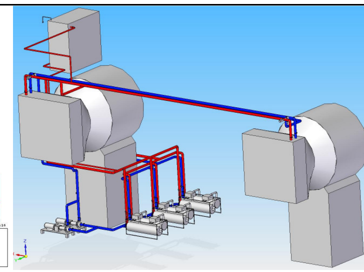
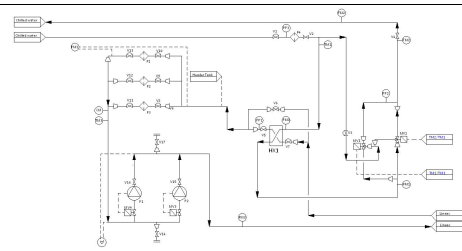
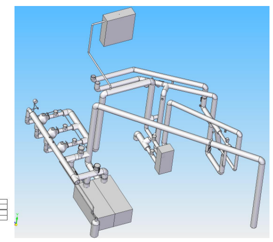
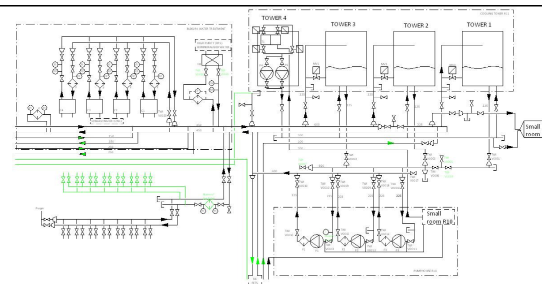
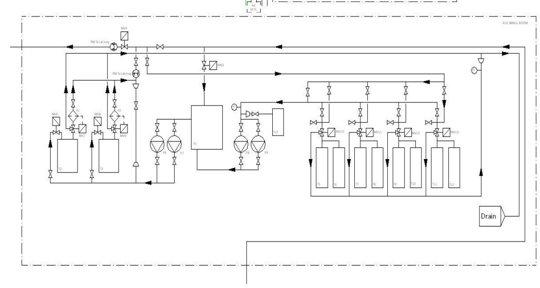
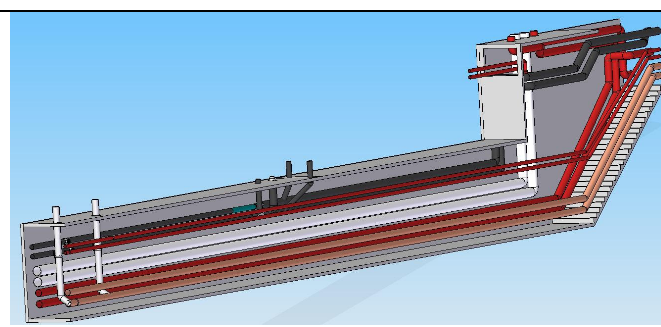
The third way of the circuits is used to transport the water to the R6 and R7. The circuit starts in the tunnel 6 and finishes in the tunnel 7.

- The HP2:

The HP2 circuit begins in the ST18 located in the R55 and it is filled with the DM1 circuit. This HP water is cooled by the heat exchanger (HX13) using the TW. Finally, the HP2 is used to provide this type of water to six biased regulators placed in the R5.4.

8.3. Work carried out

With the following table the updated schemes and 3D models developed during the internship are going to be shown. These drawing are related with the cooling system.

Location	Circuit	Drawings
R4	Chilled Water	 
R5.1	Chilled Water	 
R10, R11, R4	Tower Water	 
R4 tunnel	All the circuits	

For more information about the drawing, they are located in the appendix.

9. R55's tunnel

This tunnel is used to make available the supply of the cooling, electricity and compressed air systems of the target and the instrument and it is located in the R55 building. It has three areas: the North tunnel, the South tunnel and the sort passageway which connects the North and the South tunnel.

The tunnel was built in the sixties at the same time that Nimrod was built, the previous ISIS. Since this period the tunnel has been refurbished more than once. As a result, the old 2D drawings nowadays do not show the present tunnel. For this reason a new 3D model was created.

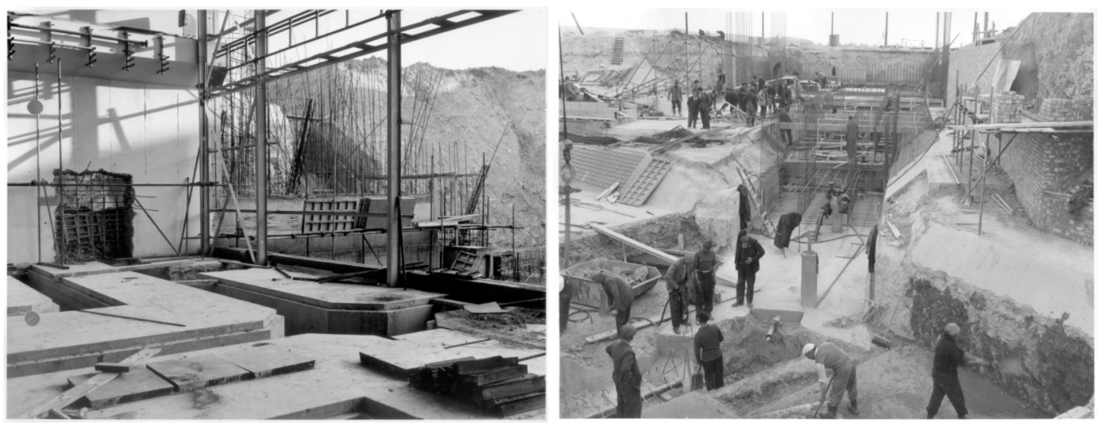


Figure 23: Building the tunnel in the sixties.

9.1. How the 3D model was done

In order to create a 3D model of the tunnel, the following steps were carried out. First of all, the old drawings (from the sixties) of the tunnel had to be found. After the search, the sketches were analysed to start creating the main structure in 3D. Once the framework was finished, the tunnel was checked point by point to find the changes that were implemented in those years. To finish updating the tunnel, changes were introduced in the 3D model.

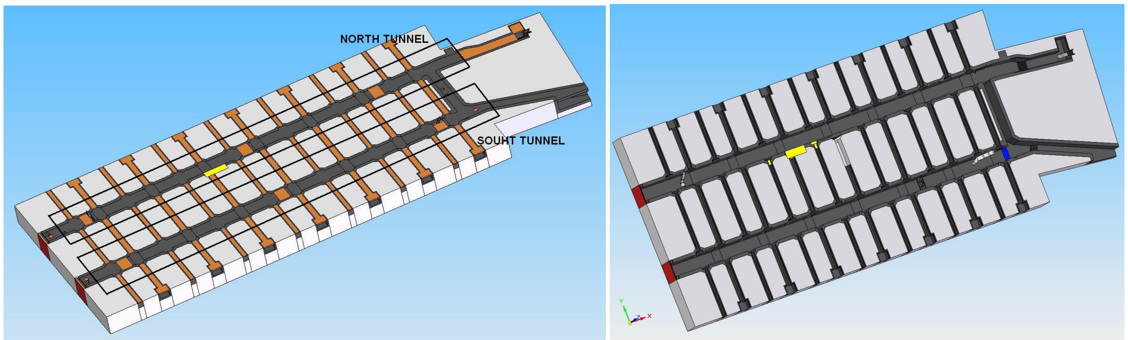


Figure 24: R55 tunnel

9.2. Circuits of the tunnel

The tunnel has plenty of circuits inside, such as:

- The tower water circuit.
- The chilled water circuit.
- The demineralised water circuit.
- The high purity demineralised water circuit.
- The compressed air circuit.

Most of the circuits were explained earlier, because the majority of them belong to the cooling system. However, the compressed air circuit is another important system in the facility. It provides the compressed air for the instruments and apparatus of the TS1.

The system consists of two air circuits, a guaranteed compressed air and a standard compressed air. The two systems go through the same places: the north tunnel and the south tunnel.

The standard compressed air circuit is the simplest one, it only has a small number of elements, such as: filters, drainers and lubricators. On the other hand, the guaranteed compressed air is much more complicated than the first circuit. It has more secondary circuits and inside them there are the following elements: filters, drainers, lubricators, two compressors, air receivers and a beam diagnostics subsystem.

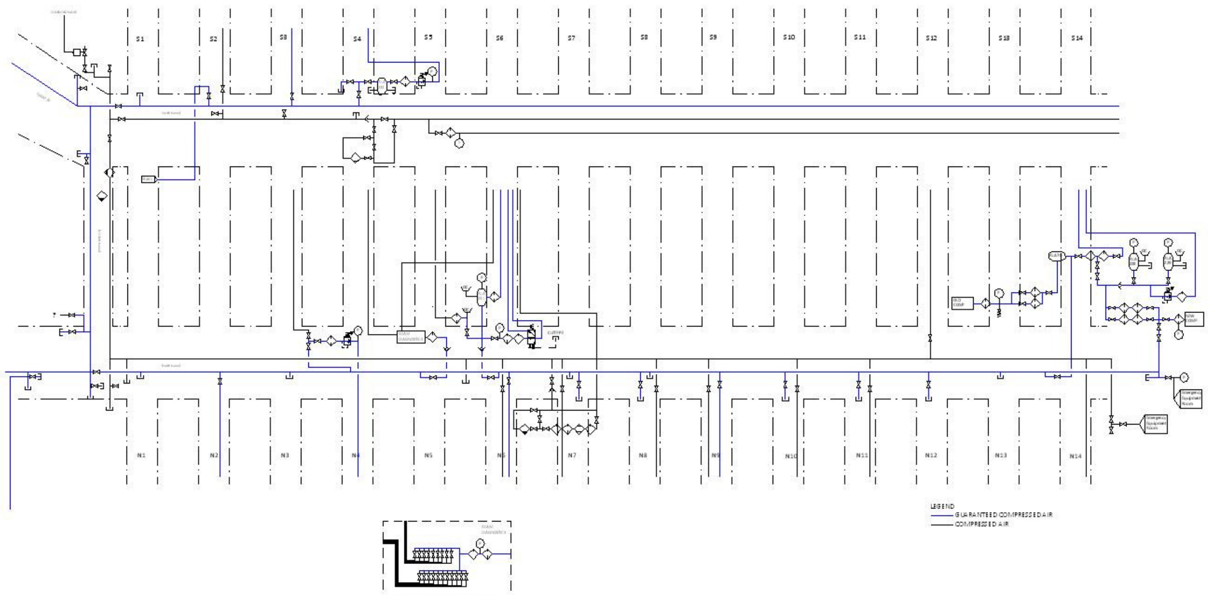


Figure 25: Compressed air and guaranteed compressed air circuits

9.3. Parts of the tunnel

As the tunnel is in a radioactive environment, it has a few significant differences from the other tunnels of ISIS. In this tunnel the security aspects are especially important, because if something happened in the target, the tunnel should be evacuated immediately. The most relevant areas are the access areas and the areas which are more exposed to the radioactivity.

- Access areas:

The access areas have to be located in specific points. They must not obstruct the instruments, but at the same time, they have to be useful in case there would be a radioactive hazard. The tunnel has six places to access inside. Five of them are located in the R55 and other one is in the continuation of the south tunnel.

The location of the five entrances in the R55 is shown in the next list:

- The entrance NO 1: Is located at the beginning of the north tunnel, next to the three pumps of the DW1 system.
- The entrance NO 2: Is located a few meters before from the end of the north tunnel, after the target.
- The entrance NO 3: Is located at the end of the north tunnel. It is a small gap opened in the ceiling of the tunnel. Nowadays is covered and it does not have a staircase.
- The entrance NO 4: Is located in the south tunnel, next to the link tunnel between the north and the south tunnel. It is also near the muon facility.
- The entrance NO 5: Is similar to the entrance N. 3, however, this entrance is located in at the end of the south tunnel.

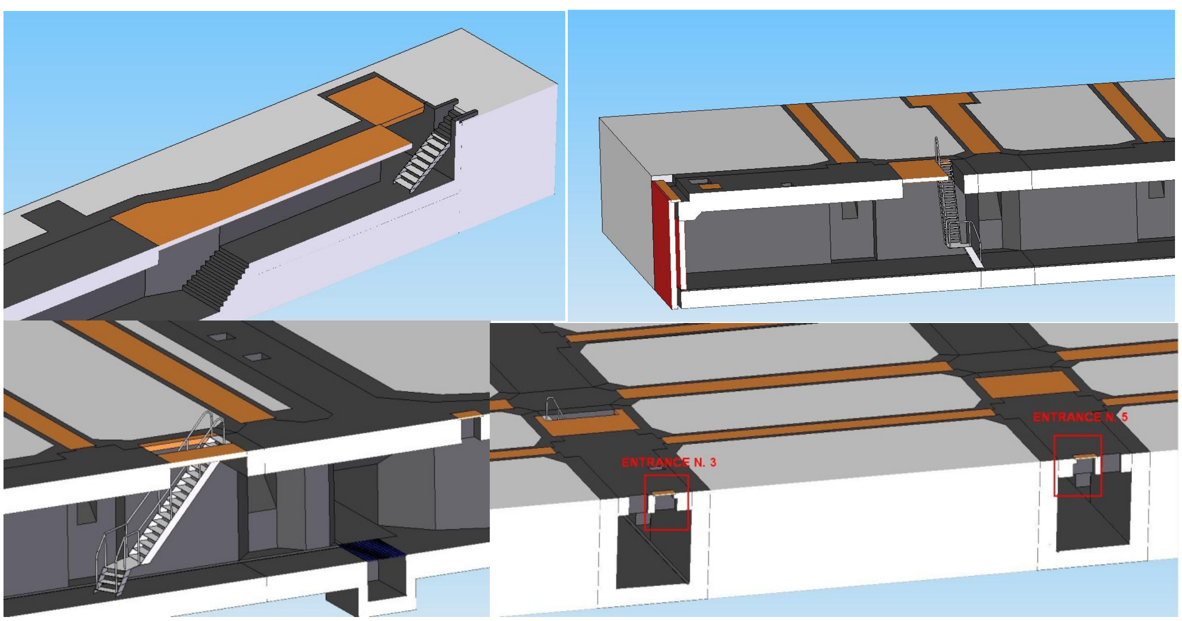


Figure 26: The Entrance N. 1, the Entrance N. 2, the Entrance N. 4 and the Entrances N. 3 and N. 5

Finishing with the entrances, the last one is the connection between two tunnels. These tunnels are the south tunnel and the tunnel 3B. The connection is placed at the beginning of the south tunnel and through the next tunnel the workers access the synchrotron.

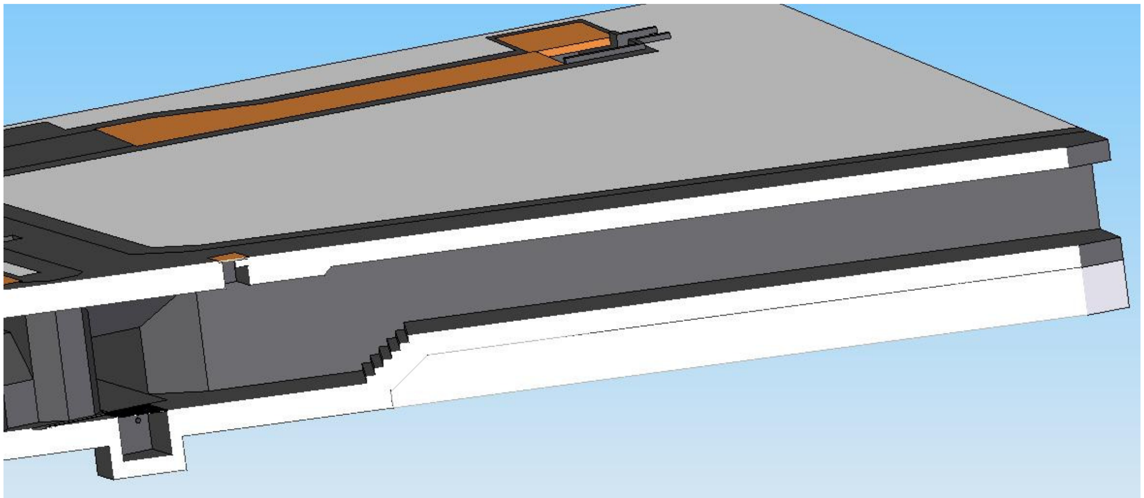


Figure 27: Connection between two tunnels.

- Exposed areas:

In the tunnel there are four specific places where the radiation hazard is higher than the maximum authorized by the specialists. These areas are at the end of the south tunnel, the link tunnel, the small room next to the target and the surrounding area of the target. As a result, these places have to be controlled and sometimes isolated to prevent possible risks.

    - The end of the south tunnel:

This part of the tunnel is a restricted area because the radioactive dose that someone could be exposed to here is very high. Consequently, everybody needs special permission to enter this section of the tunnel. To prevent the risks, the area is delimited with a chain-link fence.

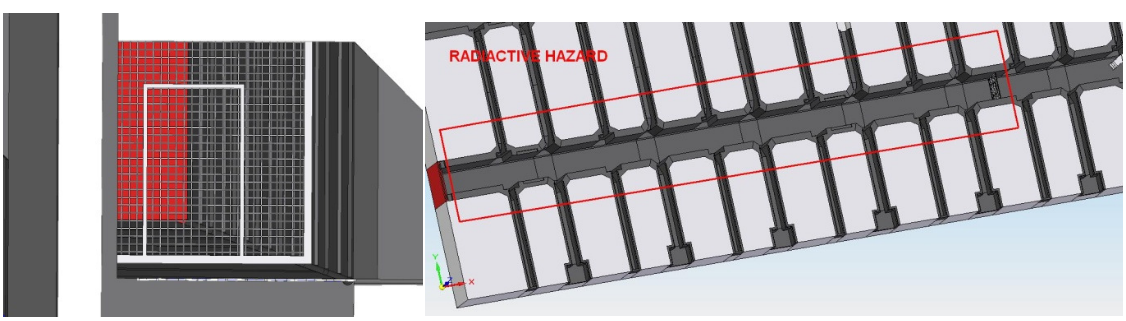


Figure 28: The chain-link fence and the area.

- The link tunnel:

In this tunnel the radiation dose is not as high as in the other exposed areas, however, it is higher than in the rest of the tunnels. The reason is because the beam line passes over the top of the tunnel. As a result, some of the particles could go through the tunnel and reach the workers. This tunnel is not a restricted area, but it is recommended not to spend a long time there.

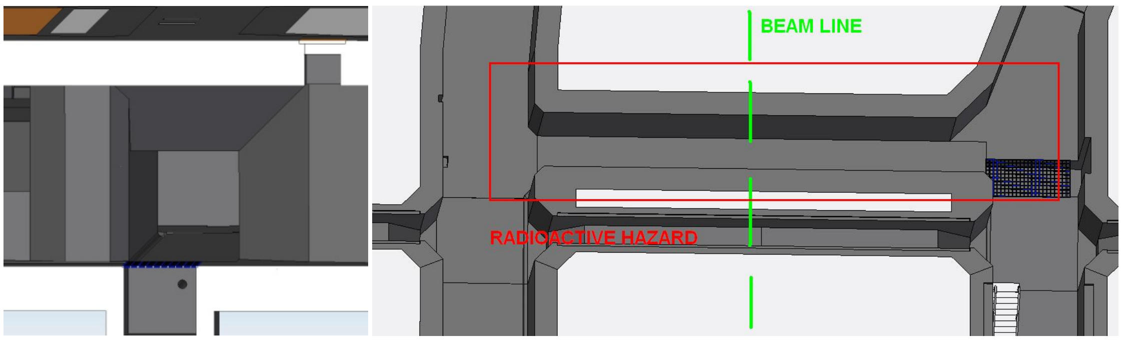


Figure 297: The link tunnel.

- The small room:

Next to the target there is a little room which was built after the tunnel had been built. This is, as it's at the end of the south tunnel, also a restricted room. For this reason only authorized people can go inside. It also has a chain-link door to avoid the entrance to anyone. The reason of the hazard is the closeness of the target. As it is only a few meters from the target, the produced neutron can easily cross the concrete. Therefore, it becomes a dangerous place for people.

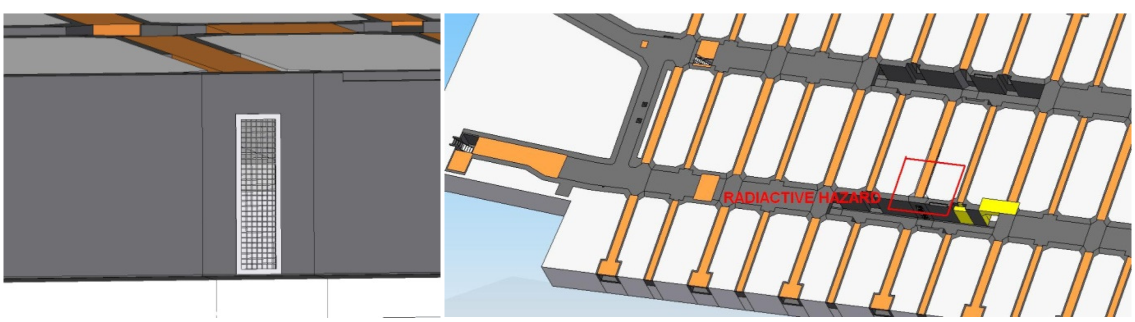


Figure 30: The chain-link door and the area.

- The surrounding area of the target:

This place is the most hazardous one in the tunnel. For this reason, all the gaps, which are used to provide electricity, water and compressed air to the instruments, are walled in. With the addition of the concrete the particles cannot cross the wall and the tunnel becomes safer.

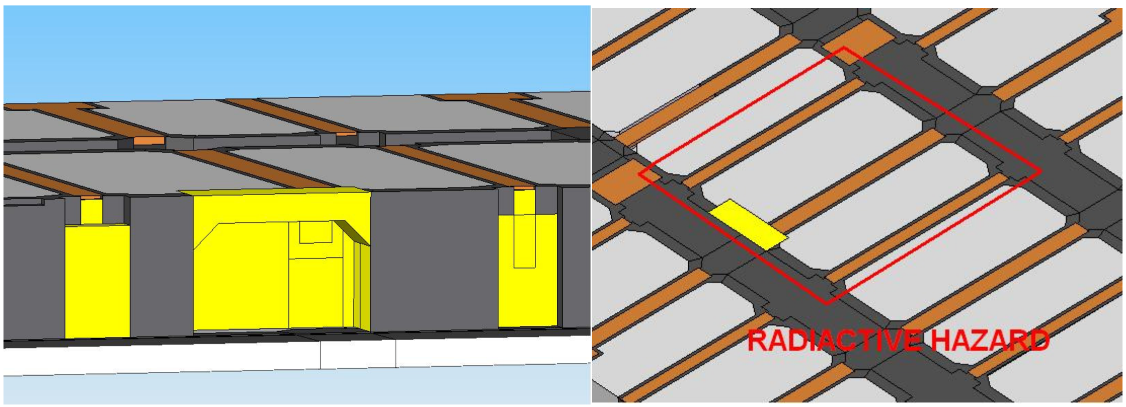
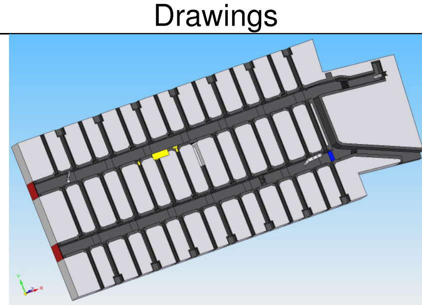
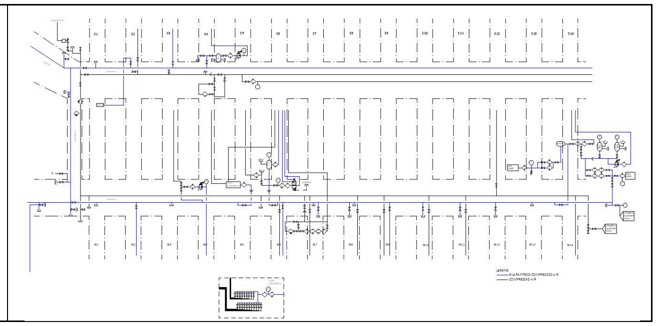


Figure 31: Walled in gaps and the area.

9.4. Work carried out

With the following table the updated schemes and 3D models developed during the internship are going to be shown. These drawing are related with the tunnel located in the R55.

Location	Circuits	Drawings
R55 Tunnel	All the circuits	

R55 Tunnel	Compressed air and guaranteed compressed air circuits	

For more information about the drawing, they are located in the appendix.

10. Layout of the pump room

The pump room is used to pump the water used in the TS2 and it is located in the west side of the TS2, on the second floor. It was designed when the TS2 was being built but during the last years some problems have been encountered. These problems were analysed and a few improvements were developed.

10.1. Actual layout

The layout has two different areas. The first one pumps the chilled water (CHW) and the second one the process cooling water (PCW).

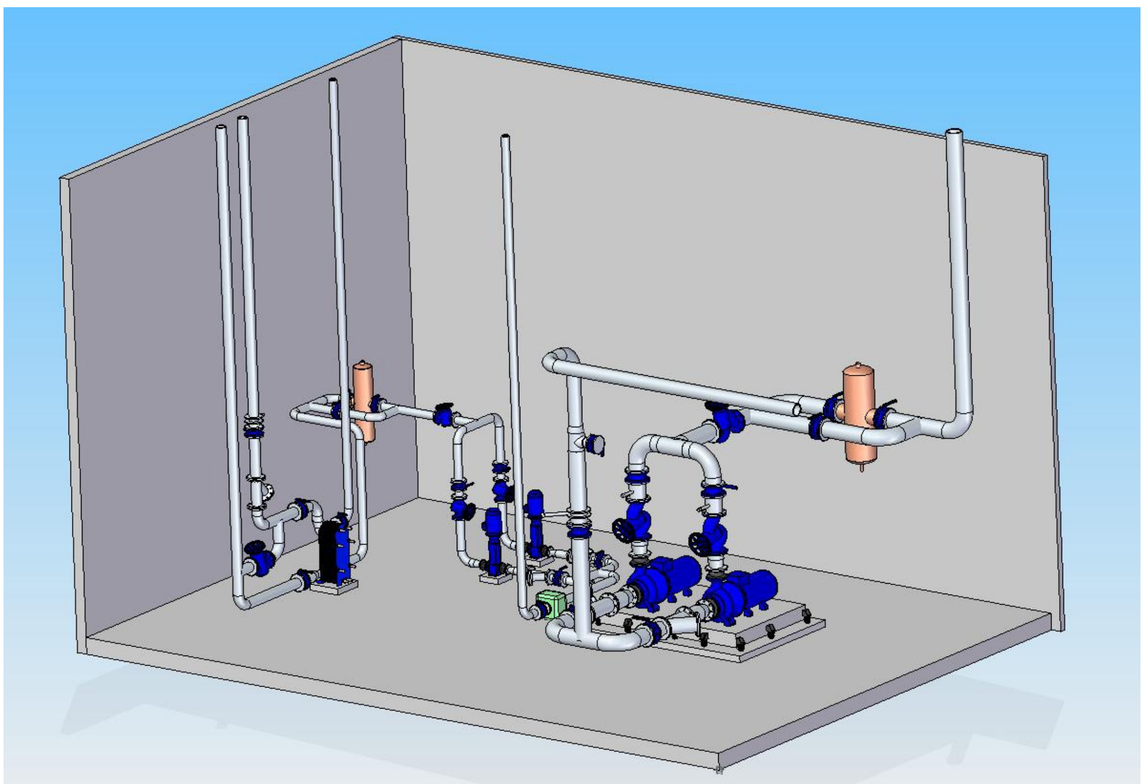


Figure 32: Pump room before

The function carried out in the first circuit is to pump the CHW. This water is the already heated water that comes from the machineries. Once it is pumped, the water is sent to the three chillers situated on the fourth level. As a result, the water is cooled again and sent to the equipment.

Two pumps are placed in the first area, each one with 75 kW of power, and an air-dirt separator. These three elements are connected by several pipes with diameters between 250 mm and 200 mm. The pumps are located in the north area of the room and the air-dirt separator is in the north-west side. As the life span of the pumps is about five years, both pumps are connected with a parallel scheme. This scheme is used to make the bypass possible. With this technique it is possible to replace a broken pump with another new pump without stopping the cooling system, or the target station. On the other hand, the air-dirt separator is used to clean the water of the cooling system and to remove the air that might appear. This is a very important matter because the facility is very sensitive to impurities in the water. The air-dirt separator is also connected with a bypass for the same reason as with the pumps.

The second circuit is used to pump and cool the PCW. This water is used to cool the process of the cooling of Helium (He) compressor. The heat exchanger uses the chilled water produced in the cooling towers to cool this water.

In this area there are two pumps, each one with 11 kW of power, an air-dirt separator, a filter and a heat exchanger. The majority are located in the south area of the room except for the two pumps and the filter, which are in the middle area. The pumps are connected in parallel and the air-dirt separator is connected with the bypass. The rest of the circuit is connected in series with pipes with the diameters between 150 mm and100 mm.

10.2. Located problems

The problems encountered in the room are related to next topics: location, water's drain, security and soundproofing.

- Location:

The location is the worst problem of the room. The layout was designed when the TS2 was being built, so the assembly of the room was easier than nowadays because the outside walls had not been finished at the time. Because of this, all the elements were settled into the room from outside, and the engineers did not think to the future, when the elements would have to be positioned from inside into the room. As a result, the assembly which was easy in the past, is nowadays more difficult, so there is a need to redesign a new layout.

The two huge pumps are the main problem. They are the heaviest elements in the room and in the present location, if they have to be removed, it will be a very complicated work. Also, it is difficult to get inside the room with any type of instrument and to move around easily because there is no area to manoeuvre, the pipes are all around the room.

The tanks are another problem. They are not as heavy as the pumps, but their large dimensions will become a problem, if they have to be changed. The difficulty appears in the height where the tanks are connected in the circuit. Therefore, it is essential to use some kind of ladder or if it is possible something similar to a “fenwick”. However, the last option is not possible since the equipment and pipes of the room do not leave enough space.

- Water drainage system:

In this case the problem is a lack of a drain system. In the room there is nothing to drain the water and if the water circuit breaks down, the water will accumulate in the room. This would be a huge problem in the facility because the flow of the water is considerable in the pipes and it would fill the room with water in a few minutes. Once the room starts to fill with water, the machinery which is in the room would most likely break down, since the equipment use electricity so it would create a short circuit. If this happens, the damages in the circuit will be important as the majority of the equipment would have to be changed.

Moreover, if the water comes out of the room it could damage the rest of the machinery in the facility as well, and in the worst case, some of the instruments in the TS2.

- Safety:

This aspect is one of the most important items in all types of facilities, for the reason that any worker can harm themselves. In the room there are quite a few details that could cause problems.

The handles of the valves are one of the problems. Some of them are too exposed and dangerous of a bumping into them and as a result the person can fall on the floor or get hurt.

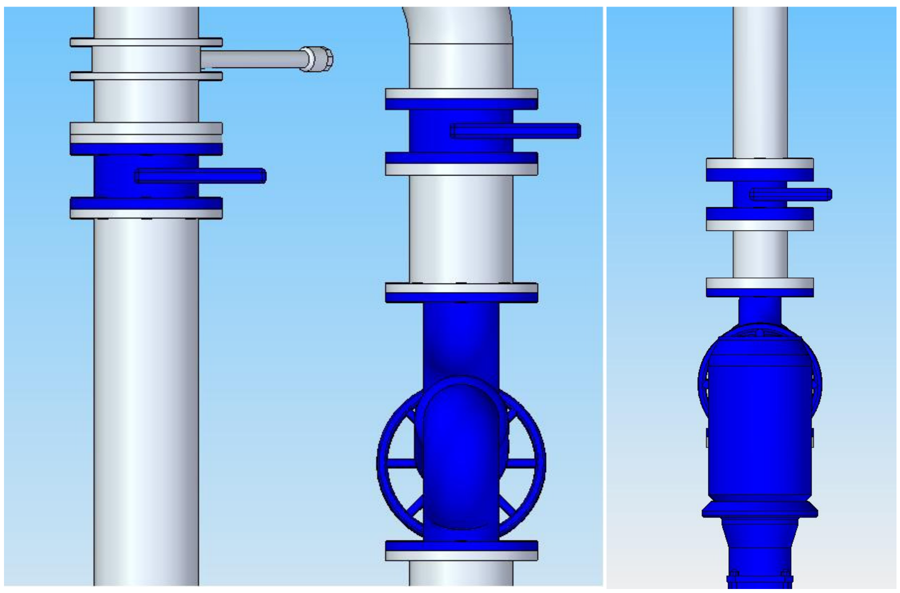


Figure 33: Dangerous handles.

The location of the valves is another problem of the room. A small number of valves are positioned in hard to reach areas so if a worker want to manipulate them, they put themselves at risk because they can lose balance and fall. Besides, there is an especially delicate place where the pumps are below the valve so if the workers lost balance, they would fall onto the pumps.

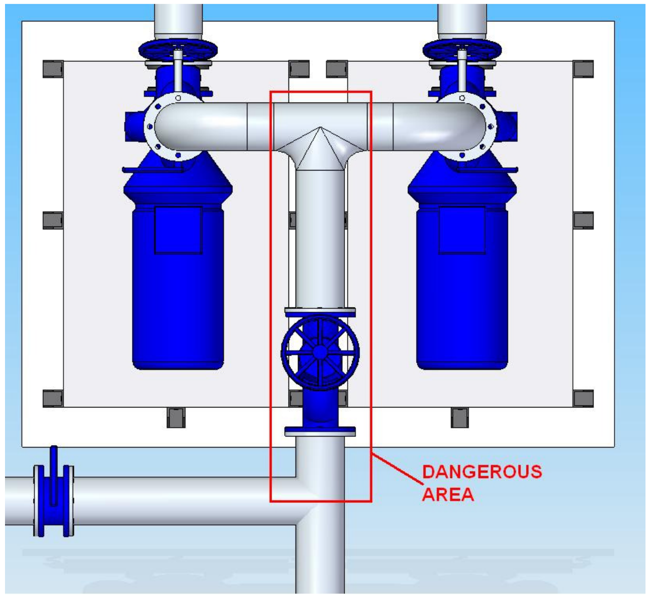


Figure 34: Valve in wrong position.

- Soundproofing:

The soundproofing is another important aspect in the room. Some of the equipment generate a circular movement, the four pumps. As a result, they produce an irritant noise that can be harmful to workers' health. At the beginning the noise does not sound as harmful as it is, but if the worker has to be in the room for a long time, they will feel the consequences.

10.3. Different solutions

To find the best solution for each problem, more than one solution was investigated for each problem. Therefore, the best solution is carried out.

- Location:

In order to improve the location of the pumps a few designs were considered. Several of them consist on moving the four pumps to another position reducing the problems that were there before. Others consist on moving some of the pumps and leaving the others in the same position and the last option was to change the position of two pumps and also to change the orientation of the other two.

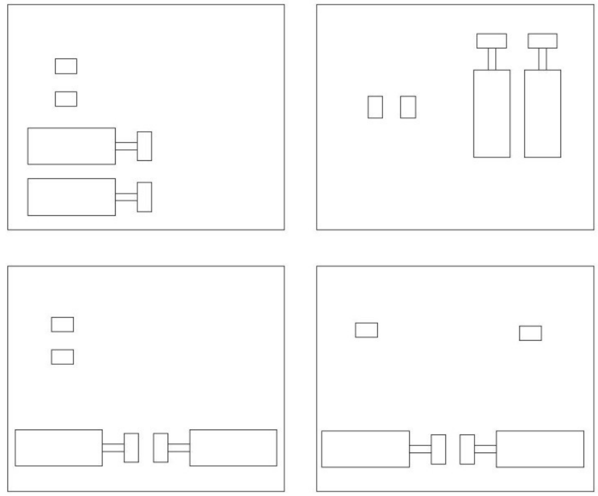


Figure 35: Possible layout of the pumps.

To relocate the two tanks, some options were considered. The first preference was to put them down, on the floor level. This choice had other alternatives: to place the tanks next to the wall or to bring the tanks closer in the middle of the room. The second alternative was to keep them on the same level but change the location. The desired location was in an equivalent position, but one level above.

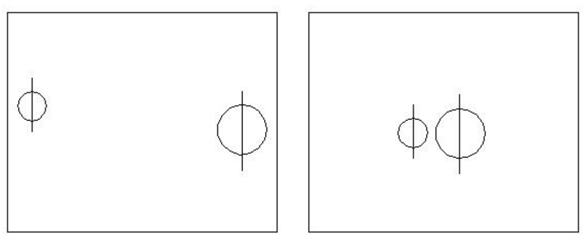


Figure 36: Possible layout of the tanks.

Another solution was considered which was not related to the location. However, the improvement would help to change the equipment in the room easily, which was the main idea. This idea consisted in building a structure using UB sections (IPN) to move the four pumps in an easy way. Movement will be by picking up the pumps and displacing them along the way of the section. Some of the designed schemes are below:

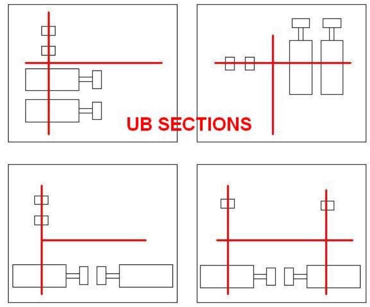


Figure 37: UB section schemes.

- Water drainage system:

In the case of the problem with the drainage system, the planned alternatives have two main ideas in common. The first one is to install a drainage system. Here, there was more than one variable according to how many drains were required in the room and where the drains were installed. The number of drains was thought to be between one and two. Moreover, the orientation of the drains was also set out, to put them in “horizontal” or in “vertical” direction. The second main idea was developed to improve the first solution. The idea was to give an inclination to the floor to collect the maximum water through the drains. The inclination angle had to be decided, but it would be from 0.5° to almost 4°.

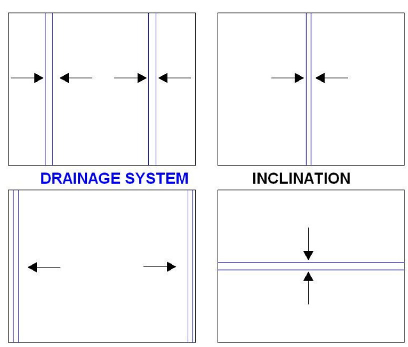


Figure 8: Drainage system.

- Safety:

The easiest way to solve the problem with the handles of the valves is to interchange the position of the problematic valves. With this simple change the handles would not be in the places where someone could bump into them.

To avoid the hazard areas with the valves, a redesign was done. However, the main idea of these changes is to keep the valves out of the perimeter of the pumps area. These designs are directly related with the new layouts of the pumps and of the tanks. Consequently, this redesign would be the last one to be carried out.

- Soundproofing:

There are a few possibilities to protect the workers from the noise. One of them was to cover the four pumps with a soundproofing box. The other one was to cover just the two big pumps. As they were the noisiest equipment, it would be enough to remove the noise from both pumps.

10.4. Final layout

When all the possible solutions were checked and compared with each other, the most appropriate solutions were chosen. With these solutions the new layout was developed and problems were resolved.

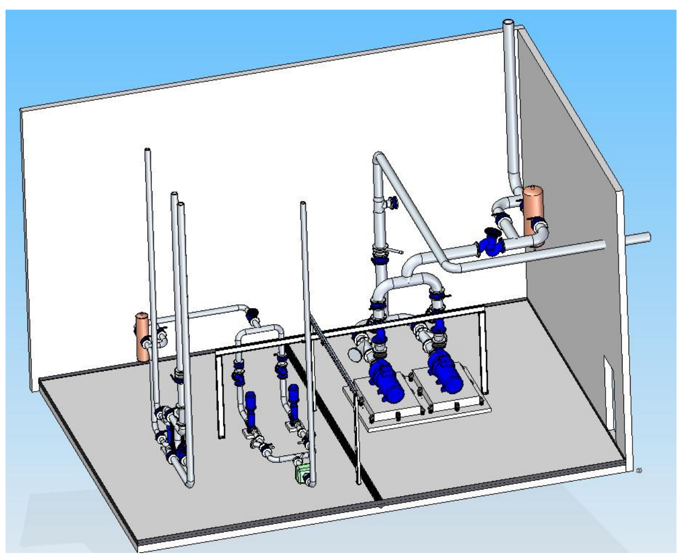


Figure39: Final layout

- Location:

The final solution of the pumps was to put the two big pumps in the same location but changing the position. As shown in the picture 39, the engine of the pump in the first layout was at the back and now is in the front. In this way it is easier to replace the pump if there is a need to do so.

To make the replacements easier, a UB section structure is built. The structure has two beams, one is located above the four pumps, the four pumps are resituated in the same row, and the other is placed on the top of the first beam in the middle of the room. The reason for choosing this scheme is due to the cheaper structure. Some of the designed structures had more than two beams, consequently they would be more expensive than the chosen one.

The first beam is used to pick up the equipment and to transport them to the second beam. On the other hand, the second beam is utilized to move the equipment from the middle of the room until the free area placed at front part of the room. As a result, the replacement of the pumps is much easier than with the old layout.

The tanks are also resituated. The chosen solution is to move the two tanks next to the walls. This improvement helps to keep the pipes closer to the perimeter of the room. Therefore, the centre of the room becomes more available to use for other purposes.

- Water drainage system:

To fix the problem with the drainage system, a drain is installed in the centre of the room. The drain is between the two big pumps and the two smalls. The reason for choosing this design is due the fact that the water collect better and it is the cheapest possible set up. The set up is cheaper because there is just one drain and not two or more like in some of the possible design.

To make the most of the drainage system, a little inclination is set in the floor. The inclination goes in a negative angle from the two walls, the west wall and the east wall, to the middle of the room, where the drain is located.

In the perimeter of the room, where the wall and the floor are joined, a chamfer is set. The chamfer makes the leak difficult, for the reason that the possible gap between the two surfaces disappears.

To dismiss totally the leaks, a waterproof membrane is installed in the in the floor. Taking advantage of the floor change, as a result of the set of the inclination, the membrane is established between the old floor and the new one. The membrane also has an inclination to be able to transport the water in better way. The inclination, as the new floor, is headed for the drain to collect the water in the drainage system.

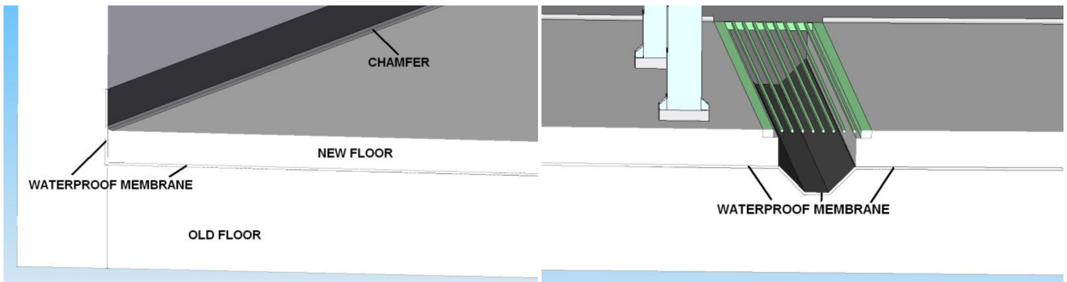


Figure 40: Waterproof membrane.

- Safety:

The valves which have the handles in the wrong position are interchanged. With this simple action it has improved the safety of the room.

The other problem is solved placing the hazardous valves outside of the perimeter of the pumps. This solution is easy to carry out because the tank is also moved next to the wall. As a result, there is enough room to locate the valves in a correct position.

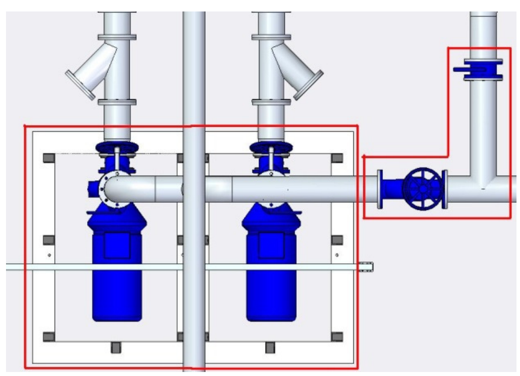


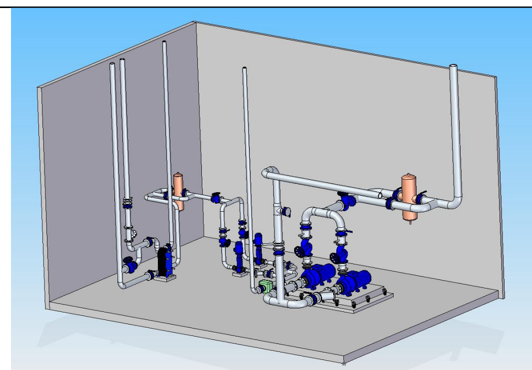
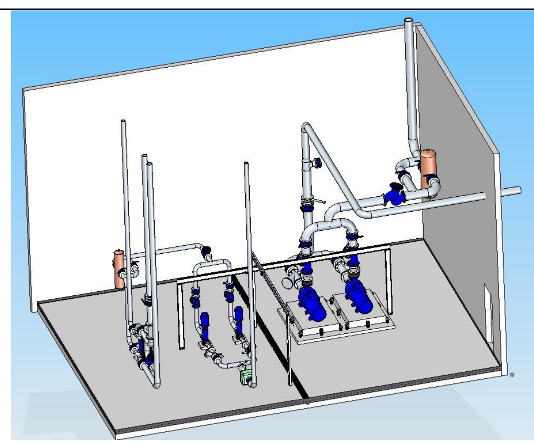
Figure 41: Valves in the correct position.

- Soundproofing:

After checking the noise from the two type of pumps, a soundproofing box is installed covering just the two big pumps. The noise of the big pump is more harmful than the small one, as a result installing just one box the problem is solved. Moreover, if two boxes were installed, the price would be increased and also would be more difficult to fix the two small pumps.

10.5. Work carried out

With the following table the updated schemes and 3D models developed during the internship are going to be shown. These drawing are related with the layout of the pump room located in the TS2.

Location	Circuits	Drawings
TS2, Level 2	Chilled water and process cooling water	
TS2, Level 2	Chilled water and process cooling water	

For more information about the drawing, they are located in the appendix.

11. Final conclusions

The final conclusions are divided in two groups. The first one is related to the updating of the documents and the second one with the design of the layout.

It is necessary to keep the information and drawings updated is the principal idea obtained after finishing the first task, the updating of the circuits. This point is essential for the maintenance the facility and for it to operate property.

There are a few reasons to support this statement. Bringing up to date the documents enables a better knowledge of the equipment and circuits of the system. As a result, the maintenance of the equiptment is easier because the calculation of the lifespan of the equipment would be faster and more accurate. Once the new information was collected in a data base, anyone could have access to the files, if they were needed; like in an emergency or in a breakage of the system.

To update the drawings shortly after the changes is suggested. If the changes were not updated immediately, the small modifications could be forgotten, the preliminary schemes could be lost, etc. As a result, the issues are piled up and when they are put all together, they become a huge problem.

To design thinking of the future also is the main conclusion developed when the second job was finished. When engineers propose something, this has to be designed to solve the present problems, as well as the problems that might appear in the future. If not a design with no issues today could become a problematic design in the future. The room redesigned in this project is a good example.

To design a layout considering problems related with the safety of the workers is another idea. This point is very important. Since the room is used by the workers, the room cannot be a hazardous place for them because the safety of the workers is indispensable. Another aim is to consider the simplest way to change the equipment after they will become obsolete. This will help to make the changes of the equipment easier.

12. Future/suggested guidelines

Two suggestions have been considered to improve the facility in the future. One of them is to progress with the modernization of the documents and the other one is to develop the redesign of the pump room.

To put a person in charge of the updating of the drawings could be the solution to finish with the modernization. This person would have the responsibility to keep the documents of the circuits updated. As a result, it would be more difficult to forget to bring up to date of the drawings and data. So the facility would not have more issues in this aspect.

To develop the drainage system of the pump room is the second improvement. This would involve the connection between the drainage system of room and the general drainage system of the facility. This point is important because nowadays the redesign does not have this connection. Consequentially, the collected water cannot be sent to the radioactive water well located below the synchrotron. This development has to be the next to be carried out to assure water treatment of the collected water.

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