VICE: R&D SUPPORT FOR A WINDOWLESS LIQUID METAL SPALLATION TARGET IN MYRRHA

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Abstract

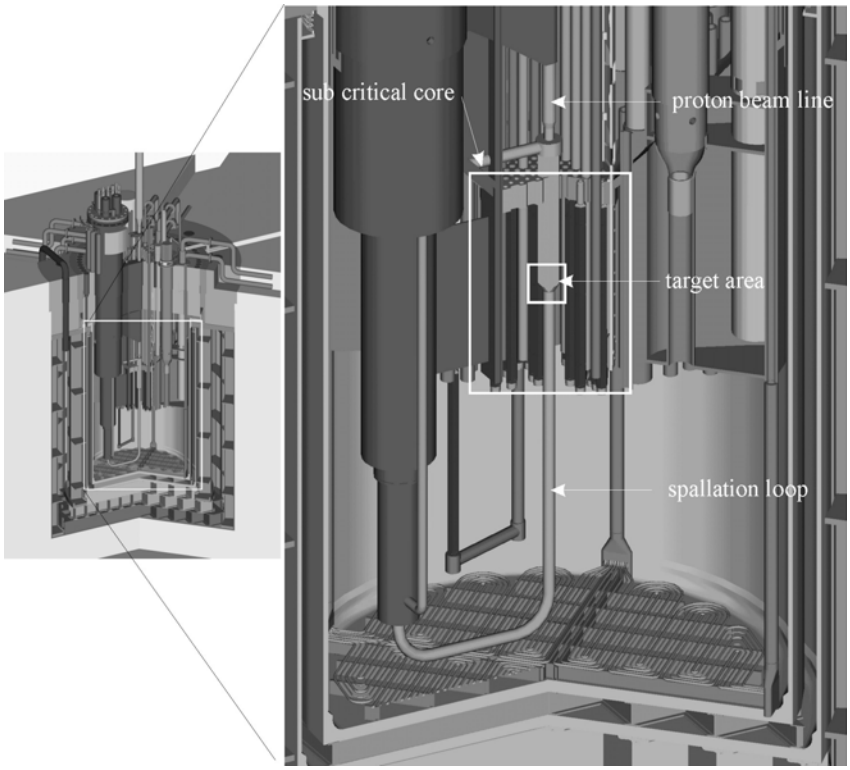
The windowless spallation target solution in the MYRRHA project is argued as the only feasible choice within the constraints of the envisaged neutron source performance. The main R&D efforts required as a result of this choice are mentioned. The Vacuum Interface Compatibility Experiment (VICE) to assess the compatibility of the vacuum interface of the proton beam line with the free target surface is discussed. A detailed description is given of the measurement strategy and of the experimental set-up that has been designed and is nearly completed in construction.

Introduction: MYRRHA ADS

At the Belgian nuclear research centre SCK•CEN in Mol, MYRRHA is being designed as a flexible accelerator-driven system (ADS) for research in a wide field of topics. [1] On the one hand, medical radioisotope production and long-lived fission products (LLFP) transmutation require a high thermal flux (10^{15} n/cm^2·s). On the other hand, materials research for fission and fusion and minor actinide (MA) transmutation studies demand an intense (10^{15} n/cm^2·s) *fast* neutron spectrum. For fusion materials research, neutrons above the (n,α) threshold energy are needed to have neutron irradiation representative of the D-T fusion reaction. MAs transmutation requires fast neutrons (>0.75 MeV) to favour fission over neutron capture. These needs are not met with "conventional" critical reactors since the highest achievable flux is about 10^{15} n/cm^2·s of which 80% are thermal neutrons. In an accelerator-driven system (ADS), combining a heavy material spallation target with a sub-critical core (SC) acting as a neutron multiplier, the absolute flux level is set by the intensity of the spallation neutron source and so, the intrinsic limitations of a critical reactor can be overcome. Moreover, a substantial enhancement of the high-energy part of the neutron spectrum is achieved.

MYRRHA ADS will use existing MOX fuel technology with the core sub-criticality level set to K_S=0.95. [2] For a given core geometry, the required spallation source intensity is fixed by these two parameters and the neutron source properties. The total power of the reactor (30-40 MWth) is kept minimal and thus the most demanding irradiation area – for MAs transmutation – is placed as close to the centre as possible. This limits the diameter of the hole in the SC, housing the target to 120 mm (Figure 1) and the proton beam illuminated area to about 70 mm since a minimal lateral target volume is needed for an efficient spallation reaction. With the core lay-out, properties and neutron spectrum fixed, the required flux at the spallation source is nearly $2\cdot10^{17}$ n/s. To reach this, a suitable beam energy and intensity must be chosen with a preference for higher energies as the neutron yield per proton increases faster than linear with energy. In MYRRHA, the beam energy will is chosen to be 350 MeV. This is about the maximum to which existing high-current cyclotron technology can be extrapolated without an excessive cost increase. The matching beam intensity is 5 mA leading to a current density of about 150-200 μA/cm^2. This is over a factor three more than in other attempts for a window design for spallation sources which are already pushing present day technology. This clearly shows that within the given frame, a window between target and beam line is not feasible in MYRRHA and that therefore a windowless design is the only option. It may be noted that also for other applications of high-power accelerator beams, a windowless target would avoid difficulties with the frequently needed replacement of the window due to high radiation damage that results from the proton beam passing through. In addition, a windowless design removes the uncertainties in the operation of a window thereby eliminating a possible window failure. In the present design, the total beam power is 1.75 MW, of which, 80% is deposited as heat in the target over a depth of 13 cm in a primary absorption volume of about 0.5 l. The only way to remove this heat to the heat exchanger is by forced convection in a circulating loop of liquid target material. For MYRRHA, Pb-Bi was chosen since it combines the requirement of heavy target material with a rather low meting point of only 123°C. In the loop, an impeller pump drives the liquid to a mass flow rate of ca 100 kg/s resulting in a velocity at the target of 2.5 m/s. This is sufficient to limit the temperature increase of the target material from a normal inlet temperature of 240°C to less than 100°C on average.

Figure 1. **A cut-out of the lower part of the MYRRHA reactor vessel**



MYRRHA windowless spallation target and the vacuum interface

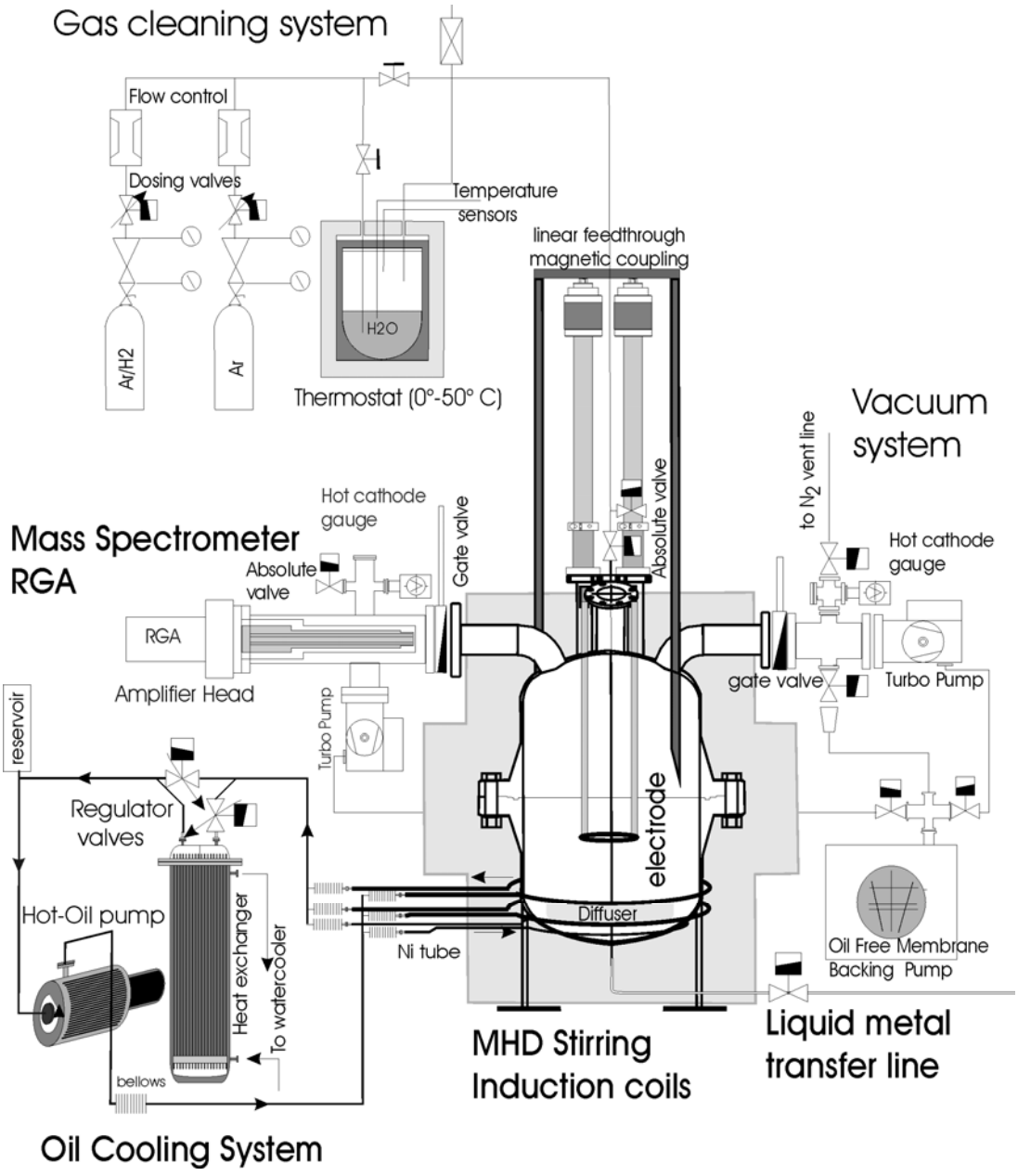
The combination of the hot liquid target material and the windowless design raises two major issues that need to be resolved. Firstly, the liquid flow of the target will form a free surface on which the proton beam impinges. Since in MYRRHA there is no window to define the target surface and position, it is necessary to control the Pb-Bi flow accurately in order to keep the target volume in the centre of the SC and to obtain the desired surface properties. This problem is the topic of a separate R&D effort within the project. [3] Secondly, the absence of a physical separation between the beam line and the beam line implies that both will have a common vacuum. The high temperature of the liquid surface causes initial out-gassing, liquid metal evaporation and later emanations of volatile spallation products from the target surface. In its wings, the proton beam, present during operation, will generate secondary electrons from the beam line walls and trigger an ionisation cascade in the residual gas. Both processes will eventually cause the formation of secondary plasmas, as all material coming from the free surface will be ionised as well. In its turn, the plasma may be the source of sputtering on the inner beam line walls since both electrons and ions in the plasma will have sufficient energy to drive out atoms from the walls. Eventually a plasma formation run-away could take place leading to damage on the beam tube or even, in extreme cases, to beam clogging.

In principle, the mentioned vacuum problems can be met if the emanating gasses are removed sufficiently quickly. However, in the present design, the vacuum pumping speed (ref: hydrogen) in the direct area of the SC is restricted to about 100 l/s due to limited space as the free target surface is set in the very centre of the SC. The high radiation and temperature levels in the SC region make it difficult to implement supporting vacuum pumping capacity. Assuming that the highest allowable pressure for the proton beam in the lower part of the beam line is about 10^{-3} mbar, the maximum emanation rate is around 10^{-1} mbar·l/s matching an evaporation rate of roughly 10^{-3} mbar.l/s·cm^2. This represents 1 g of H_2 per day being emanated from near 5 000 kg of Pb-Bi eutectic in the spallation loop. Since the

amount of plasma formation critically depends on the competition between the pumping capacity and the out-gassing/evaporation rate, both have to be investigated in a realistic situation. In contrast to the solid surface used in conventional target technology, the free liquid surface is an effectively infinite particle reservoir. It is not a-priori clear to what extent volatile elements can be removed in the conditioning process of the Pb-Bi before operation of the target. In any case, the problem is too complex to be dealt with reliably on the basis of theoretical model calculations alone. However, in a first step, the emanation of all types of spallation products was estimated using a deterministic model of the vacuum pumping scheme of the MYRRHA spallation loop and beam line. It was found that this contribution to the out-gassing can easily be tolerated if the particle emanation of the free surface is less than the equivalent emission occurring when the full surface is at 500-600°C. [4] It was assumed that all volatile products are released instantaneously and no re-condensation occurs. As MYRRHA is the first ADS project to adopt a windowless design, one must obtain a quantitative experimental compatibility assessment of the free target surface with the vacuum of the beam tube that holds when the point-of-no return to construct MYRRHA has been reached. In order to perform this task, the vacuum interface compatibility experiment (VICE) set-up was built. The apparatus is largely a one-to-one ultra high vacuum (UHV) scale model representing the lower part of the beam line connecting to liquid metal target in the confined layout of the SC area. It therefore avoids the need to extrapolate the results from small-thimble experiments, which would not necessarily, scale in all respects. In the device we will study metal evaporation, emanation of volatile spallation products and the initial and long-term out-gassing of the target material. Possible compound formation and the gas transport properties of the beam line will also be studied. The main detector for this work is a high-resolution quadrupole mass spectrometer that is put near the top of the vessel. Data will be taken as a function of pressure and temperature. The measured flow rates will be calibrated by comparison with known externally introduced mass flow rates using the mass spectrometer as the differential detector. It may be noted that related work is being undertaken in the framework of the TRASCO-ADS. [5]

A second item to be assessed is the conditioning of the Pb-Bi since the data will only be relevant if the initial status of the Pb-Bi material is kept under control. Also, as Pb-Bi is corrosive on stainless steel, the vessel surface needs protection. This may be done by controlling the oxygen level in the liquid metal such that formation is avoided but stable Fe and Cr oxide formation is assisted. The latter form a protective layer on the surface of the device that retards the dissolution rate of the steel components to a tolerable level. [6] To avoid corrosion damage to the VICE vessel itself the vacuum interface compatibility study was split in two steps and an UHV-pressure preconditioning vessel was built in which to carry out this part of the programme. Here, the procedures for the initial cleaning, oxygen level control and coarse out-gassing of the Pb-Bi will be investigated. Moreover, as some questions regarding the filling method of the main MYRRHA vessel were raised, the programme was widened to help answering these as well. Although the necessity of the preconditioning vessel for the project needs is unquestionable, it did cause re-arrangement of the planning with regard to the spallation source issues and a delay in the Pb-Bi out-gassing and evaporation experiments. In the next sections, both experimental vessels, the equipment and operational procedures that will be used in the gas experiments and the present status of preparation are described.

Figure 2. **An overview of the technical lay-out of the preconditioning vessel**



The preconditioning vessel

A schematic drawing of the precondition vessel (PCV) is shown in Figure 2. The apparatus is a barrel-shaped UHV-to-10 bar pressure vessel for use up to temperatures of 500°C. The UHV feature ensures clean experimental conditions whereas the normal operational pressure is only down to high vacuum (HV) levels. The inner surface is cleaned and electro-polished to UHV standards to avoid any contamination of the PbBi material that may distort the experimental data. The thickness of the walls and the open geometry of the container allow easy mechanical cleaning and electro-polishing to return the wall surface to its initial state should any corrosion damage occur. This makes the PCV also suited to assess the filling procedure of the MYRRHA main basin, albeit on a smaller scale, and to simulate

and study a possible oxygen ingress and the subsequent reconditioning of the vessel and the Pb-Bi eutectic. Its main use, however, will be in the initial conditioning procedure of the Pb-Bi. At first, about 10 l (104 kg) of Pb-Bi is molten in the evacuated PCV. For this wire mesh heaters for large vessel areas and thermo-coax heaters for compact flanges, with a total power of 3 700 W are put on the outside of the device. Insulation is provided by a 3 mm sheet of Micropore material and 12 cm of synthetic carbon-fibre wool limiting the outside temperature to about 50°C. The vessel temperature is measured using K-type thermocouples and controlled by a Labview® based data-acquisition and control programme (DAC) via PID loop. Commissioning tests have shown that the vessel can be heated homogeneously to 1% and temperatures can be kept stable to within 1°C.

After the Pb-Bi melt, the liquid surface may be checked visually using two 67 mm inspection windows on top of the vessel. Each is closed off by a 25 mm thick quartz plate able to withstand an interior pressure of up to 1 MPa. A high temperature (500°C) UHV tight seal ($<10^{-9}$ mbar·l/s) on the window is obtained by a double set of helicoflex-type metal seals where each top-seal is fitted to avoid strain on the quartz when the seal is tightened. When surface contamination of the liquid metal is too severe – which may occur since most insoluble impurities will be lighter than the Pb-Bi and thus float – a first coarse cleaning can take place by skimming the surface. To do this the vessel must be opened under an inert gas flow while the melt is still liquid. After this first step, excess PbO must be removed by lowering the oxygen content in the liquid metal. For this purpose the PCV is equipped with a gas cleaning system. Water vapour is added to a ca 5% H_2/Ar mixture by bubbling it through water that is kept in a thermostat at a fixed temperature between 0 and 50°C. By tuning the gas flow and the water temperature the H_2/H_2O ratio that governs the oxygen potential, is set to the desired level. The gas mixture is then lead through the liquid metal where it is spread out via a sintered stainless steel diffuser. In the melt, the surplus PbO is reduced by the H_2 and the produced H_2O is carried away by the argon. A solid zirconium-oxide electrolytic cell with a Pt/Air reference system will monitor the oxygen content in the vessel. When the gas cleaning process is over, most insoluble material will have been removed. Yet, a small amount of debris may still be present on the face of the melt. To remove this, electrical glow-discharge-cleaning is foreseen. For this purpose a Cr-(coated) electrode is mounted on a magnetically coupled linear feed-through. After the chamber is evacuated, a small amount of an appropriate reducing gas that is not inherent for the investigation, e.g. deuterium, is allowed in to create a background pressure of 10^{-4}-10^{-2} mbar. A bias voltage on the electrode in the gas creates a plasma. The high-energy, as compared to thermal motions, plasma particles bombard the surface of the liquid metal and the walls of the vessel, thereby reducing and removing outer layers. This material is subsequently eliminated from vessel by the pumping system. Since the spatial extent of the plasma and plasma current critically depends on the position of the electrode, the latter is made moveable to allow optimisation of the sputtering process since as it is, in principle, only desirable to use it on the liquid metal surface and not on the walls. Nevertheless, in some situations like the preparation phase for a possible coating, complete plasma cleaning of the entire vessel may be required and the experimental means to do so have been foreseen. A 10 kW plasma power-supply with stored energy of less than 0.3 J to prevent arcing is available.

The liquid metal contained in the PCV is essentially stagnant. Nevertheless, the experiments discussed here represent a moving free surface in a liquid metal loop. Thus, it is essential to be able to renew the surface of the melt. In addition, most cleaning processes only work on good contact of the gas with the melt so, also here, surface renewal is important. In order to achieve this, magneto-hydrodynamic (MHD)–driven stirring is installed using two sets of three coils, placed in close proximity to the outside walls of the vessel. Each set is connected to the three phases of a special 50 Hz mains transformer that can provide each of the coils with up to 600 A rms current. The low frequency assures a penetration depth of the AC magnetic field into the melt of the order of a few cm. Finite element calculations have shown that e.g. at 2 cm from the inside wall of the vessel a magnetic field of up to 10 mT can be reached. Given the viscosity and density of the molten Pb-Bi this is

thought to be sufficient to create a recurrent flow in the crucible going up (down) along the walls and down (up) through the centre. The calculations were also used to optimise the position of each pair of coils with respect to the vessel contours. The coils themselves are made from 12.7 mm×1.65 mm Ni tube. Ni material is a compromise between the requirements of a minimal electrical resistance and maximal mechanical rigidity at high temperatures. During operation, the current in the coils generates a total of about 5 kW of heat, which must be removed. Yet, since the coil tubes are very close to the vessel walls, the coils should be kept at a rather high temperature to avoid cold spots in the melt. To solve this problem 3 mm of highly effective insulating material (Micropore) is put between the vessel and the Ni tubes. In addition, an oil cooling circuit driven by a magnetically coupled hot oil pump operating at 300°C and a small oil-water heat exchanger is put in to evacuate the dissipated heat. In its turn, this device is cooled by a standard compact 5 kW water cooler.

The PCV vessel is equipped with a small 70 l/s turbopump with greased bearings backed by a 3 m^3/h 3-stage membrane pump. This system yields a minimum of hydrocarbon contamination in the vacuum vessel without going for a turbopump with full magnetic bearings and has an end-vacuum capability for leak testing down to mass spectrometer conditions below 10^{-7} mbar. It can also cope with the expected emanations. The pressure readout is by a full range gauge ($2 \cdot 10^{-6}$-1000 mbar) hot-cathode/pirani whose readings are registered by the DAC computer. Both the vacuum pump and the gauge are separated from the main vessel by a 63 mm UHV gate valve since they will not withstand the envisaged 2 bar overpressure range that will arise in the main vessel during the gas-cleaning process. Finally, a 100 mm port opposite to the vacuum pump that is shut off by a UHV gate valve may be used to install the rest gas analyser (RGA) based on the triple-quadrupole mass spectrometer. Although the RGA is mainly meant to be used in the VICE experiment itself, the device can e.g. also be employed to monitor the material being dissipated during the gas cleaning process. A more detailed description of the RGA will be given in the next section where the VICE vessel will be discussed. During the conditioning of the Pb-Bi, i.e. before and after each cleaning step, the overall outgassing and evaporation flow rate will be assessed by measuring the pressure that is reached in the vessel against a known pumping speed. Alternatively, when lower emanation rates are found, the increase in pressure in the closed off vessel will be measured as a function of time while eventually, the RGA may be employed as mentioned above. It may be noted here that also the qualitative appearance of the eutectic mirror will act as an important guide in the cleaning process. In the development of the conditioning procedure, these data will be taken after repeated subjection to air and subsequent application of the different cleaning methods. Once the cleaning and conditioning process is complete, the liquid metal can be shifted to the VICE vessel. For this purpose a 6 mm stainless steel tube connects the bottom of the PCV with the inlet port in VICE. On both sides, the transfer line is terminated by a diaphragm valve allowing a transfer temperature of up to 200°C. In order to be able to transport the PbBi mainly by gravity, the PCV is positioned on a platform such that the bottom of the vessel is about 2 cm above the level of the inlet port in VICE. However, the possibility exists to pressurise the PCV vessel during the move with an inert gas that is eventually used at the end to the transfer procedure to purge the transfer line.

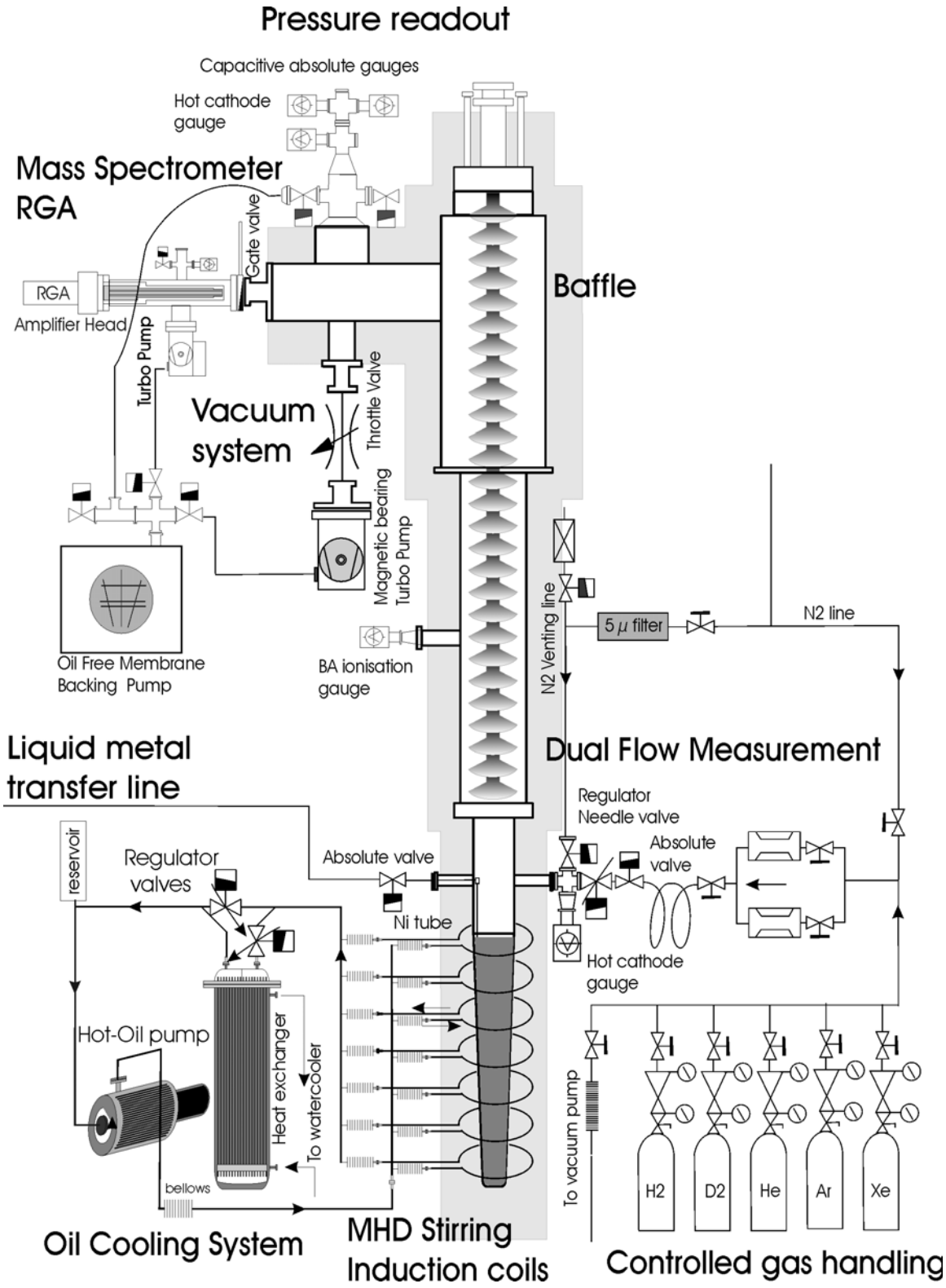
The VICE vessel

The VICE vessel is a 5 m high elongated UHV chamber resembling the lower part of the proton beam line near the liquid metal target. A schematic drawing of the device is shown in Figure 3. At the bottom of the column the Pb-Bi, coming as pre-treated from the PCV, is stored in a 900 mm high crucible containing a volume of about 10 l (100 kg). The entrance point of the transfer line is at the lowest port above the surface level of the melt. The line itself continues to below the surface level to ensure that any material added later on (like e.g. tracer Hg) is deposited into the melt. In its top part, the VICE vessel holds a ca 3 m long baffle system that is installed to give VICE a conduction rate

limitation for the assessment of flow rates and to possibly limit (retard) the migration of the (condensable) metal vapours to the top. It consists of 36 truncated cones with a base diameter of 240 mm and an 80 mm free bore. Thermocouples are installed on the baffle that can be cooled or heated independent of the vessel by circulation liquid of the correct temperature through a built-in circuit. It is foreseen to mount a microbalance based on a quartz oscillator to assess the evaporation and outgassing rate of condensable materials in the free bore. In addition, dismountable surface elements on the baffle will permit post mortem investigation of deposits on test areas. At the very top, a single window is placed, similar to the ones on the PCV. Besides visual inspection of the melt surface, it allows experiments concerning laser based level detection (LIDAR) that could possibly be carried out in VICE in preparation for the real level monitor to be employed on MYRRHA. As with the PCV vessel, the inner surface of VICE is electro-polished and cleaned to UHV requirements. However, because of the specific geometry of the vessel, reconfiguration of the surface finish after extended damage has occurred is not easy. The full VICE vessel can be baked to 500°C for experimental and possibly coating purposes. The heating system on the vessel, including temperature measurement and registration, is similar in operation to the one on the PCV. Only here, a total heating power of 7 kW is installed and more thermocouples are required. Also the MHD stirring device is similar as before. In the case here, 9 or 12 coils are installed because of the elongated shape of the crucible. Each of these is connected alternately to one of the three phases of the 600 A mains transformer. A glow-discharge cleaning electrode can also be installed in the VICE vessel, albeit in a fixed position. It will, however, solely be used for minor corrections since the bulk of the conditioning should already have taken place in the PCV. This is also the reason why process gas cleaning is not foreseen.

At the top of the vessel a 400 l/s magnetic bearings turbopump with an integral Holweg stage, able to discharge against 10 mbar, is placed. To ensure that the total pumping speed is dominated by the dimensions of the vessel and not by the pump, the pump is oversized compared to the geometrical pumping speed of the vessel of less than 100 l/s (H_2 value). As forepump, a 3 m^3/h membrane pump is employed, identical to the one on the PCV. Both pumps are connected to the same forevacuum line. During standby operation when the vacuum in one set-up only needs to be maintained, these pumps are acting as backup for each other, giving additional safety for long-duration measurements. It is however possible to separate both forepumps and use them simultaneously if need be, e.g. during experiments to avoid back draft of gases or pump-down procedures. The combination of a magnetic bearings turbopump and a membrane pump prevents any hydrocarbons entering the vacuum since the pumping system is completely oil-free. Still the pump is able to provide the vessel with initial clean UHV conditions reaching an ultimate pressure below 10^{-8} mbar. At the entrance of the turbopump the pumping speed can be throttled by a calibrated variable conduction valve over nearly four orders of magnitude to almost zero. This device is implemented for flow rate measurements and to obtain a means to change the pressure over a reasonable range independently of the flow rate in the system in a stable manner. The variable conductance valve can be closed completely so that it acts as a shut-off valve (albeit with internal Viton seal). In may be noted here that – apart from a few internal Viton seals in the cold part of the measurement system – the entire VICE-PCV vacuum system is metal-sealed to the outside atmosphere. This is done to achieve an absolute He-leak-tightness (better than 10^{-9} mbar.l/s for components and 10^{-8} mbar.l/s for the system) and a maximum bake-out temperature.

Figure 3. **An overview of the technical lay-out of the VICE experimental vessel**



The vacuum gauges that provide pressure readout are not merely process control devices but form an integral part of the data taking equipment. During the outgassing and evaporation experiments the pressure over the full vessel must be known as accurately as possible. For this two hot-cathode/pirani full range gauges ($2 \cdot 10^{-6}$-1 000 mbar) are placed, one just above the liquid metal surface and one at the top end of the column. In the centre of the vessel a Bayert-Alpert (BA) ionisation/pirani full range gauge ($5 \cdot 10^{-10}$-1 000 mbar) is mounted. In addition a pair of absolute capacity pressure gauges with ranges of 10^{-4}-1.1 mbar and 0.01-110 mbar respectively, is put at the top of the set-up. All vacuum gauge readings are registered in the DAC computer. A known drawback of a hot-cathode gauge is its limited accuracy of about 30%, which is mainly due to long term drift. The capacitive gauges have an accuracy of 0.15% over their useful range while the BA accuracy is a few percent. In our set-up the hot-cathode gauges can be calibrated against the BA gauge in the low-pressure range and against the capacitive gauges in the high-pressure range. The calibration and possibly re-calibration because of contamination can practically be done by gradually changing the pressure via the calibrated throttle valve or by slowly venting the vessel through the needle valve after the pumps have been closed off. It is foreseen to calibrate the gauges for a particular type of gas using one of the species that is available in the controlled gas handling system.

The most important diagnostic tool in the liquid-metal outgassing and evaporation experiments discussed here is the rest gas analyser (RGA). The apparatus is based on a commercially available Hiden triple-quadrupole mass spectrometer. Basically the spectrometer consists of an ion source mounted at the entrance of a "tunnel" formed by 3 sections of 4 parallel rods to which a RF quadrupole field is applied. Ions produced from the rest gas in the ion source can only travel through the tunnel if the mass of the ion matches the frequency of the quadrupole field. At the other end of the tunnel, a Faraday cage for large signals and a microchannel plate for small signals are placed to measure the ion current that filters through. The amount of ions detected at a given frequency is then a measure for the amount of gas-molecules of a given mass. The mass resolution of the device is determined by the selectivity of the quadrupole filter. In our device this is enhanced by the using three separate quadrupole structures. In combination with a dedicated 0-50 amu RF generator, the RGA reaches a mass resolution $\Delta m/m > 2000$ in the 0-50 amu range. Although mass calibration of the spectrometer is relatively straightforward, an absolute signal calibration is not possible since it depends on the efficiency of the ion source, the quadrupole structure and the detector, each of which may drift for various reasons. Thus, differential calibration against a known gas flow is necessary. The mass spectrometer itself is housed in its own small vacuum chamber equipped with a turbopump and full range hot-cathode vacuum gauge. At the entrance of the RGA chamber an additional variable aperture is introduced. This makes it possible to match the required vacuum for the RGA to the experimental vacuum that is to be changed as matter of the experiments, by differential pumping. The chamber also acts as a protection for the fragile quadrupole structure and makes is relatively easy to move the RGA on either of PCV or VICE vacuum vessels.

Before the outgassing and evaporation experiments can take place the gas flow needs to be calibrated. For this, a gas-inlet port is put just above the level of the liquid metal. The gas flow is controlled by an all-metal regulating needle valve with a minimal flow of 10^{-10} mbar·l/s for pure gasses. The device can be operated both electronically and manually but is not an absolute valve. A shut-off diaphragm valve was placed in series. The mass flow is measured by a set of two differential heat transfer type flow meters with a range of up to 1 and 20 mbar·l/s respectively, both with a relative accuracy of 1% FS. The flow meters are mounted in parallel giving a total measurement range of almost 4 orders of magnitude down to 10^{-2} mbar·l/s. For lower flow rates, the needle valve calibration will be used. In the gas-handling system that provides the calibration gasses, hydrogen, deuterium, helium, argon and xenon are foreseen at present. Also nitrogen is available although this gas is taken from a supply of liquid nitrogen on hand in the laboratory. In may be noted that the calibration gases are not limited to the species mentioned here since in principle, any known gas can be used. Once a

known gas-flow is allowed into the vessel, its signal can be measured by the mass spectrometer. However, the transport properties of the gas through the VICE column (and through the beam tube in reality) will depend on the pressure and temperature. Therefore, the calibration must be done for all temperature and pressure regimes of interest that are used in the real experiment and the must be done differentially, i.e. repeated in close time-wise proximity before and after the actual measurements.

When the calibration is established, mass flow rates of emanated gases and vapours measured in the RGA in given circumstances can be linked to an evaporation or outgassing rate. The composition of the gas flow will be resolved using the mass characteristics of the gas as measured by the quadrupole spectrometer and in this way the emanated species can be identified. In these conditions the eventual experiment can be performed measuring the mass flow rates of material outgassing or evaporating from the liquid melt. These values are expected to lie between 10^{-6} and 10^{-1} mbar·l/s. The data will be taken as a function of the pressure in the vessel, the liquid melt temperature, the stirring rate and the baffle temperature. In a second stage, stable isotopes resembling the spallation products like e.g. Hg may be added to the Pb-Bi via the liquid-metal transfer line. By using the MHD stirring device the materials should be adequately mixed such that in effect the outgassing of spallation products can be simulated. Subsequently, the mass flow of the spallation product will be measured as a function of the same parameters as mentioned above. However, since the main goal of this measurement is the establishment of the transport properties of the beam line, time dependence will be an additional factor and therefore the additional material will have to be inserted in a pulsed mode. The experimental data gained in the above way will serve as input into the modelling of the interaction of the proton beam with the emanated gasses and vapours in order to eventually assess the plasma formation problem described in the introduction.

At present, the commissioning and testing stage for the vacuum vessels and instrumentation is well underway with the main effort being concentrated on the charging of the pre-conditioning vessel to commence soon. The most important bottleneck at the moment is the operation of the MHD stirring system and the associated cooling systems. However, the first PbBi conditioning experiments are scheduled to take place within the next two months after the workshop.

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