ORNL RESEARCH REACTORS DIVISION
COLD SOURCE EXPERIMENT DESCRIPTION

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Testing Introduction

Cold source experiment (cold source) out-of-reactor testing will be performed to validate the design of the experiment, prove equipment meets its design function, gain operational experience, validate the control system, and benchmark analyses which model the various processes. Out of reactor testing will be sub-divided into two main phases. Each phase is further described in its introductory section. Desired test data will be identified prior to the test and collected during each test. Pre-test discussions will be held to facilitate coordination of data collection and test conduction, as required. Post-test discussions will be held to provide objective feedback, to improve test conduct, and to interpret results obtained from the tests. Following completion of out-of-reactor testing, the cold source moderator, beam tube and supporting equipment will be installed inside of HFIR. Phase D testing will be performed to commission the cold source. A Phase D test plan will be prepared to describe testing activities during this phase of testing.

The cold source system consists of a number of subsystems. Each subsystem will require some post-installation testing before the cold source can be operated. A Cold Source Experiment Testing Procedure will be prepared which will be the record document for the planned tests. The testing procedure will be issued and approved per RRD/Cold Source procedures.

Experiment Design

The HFIR cold source is the first forced circulation super-critical hydrogen cold source placed into a reactor. Much research and development for this first-of-a-kind and one-of-a-kind instrument has been performed. Although the components are primarily standard industrial equipment, much design and fabrication effort has been expended to achieve the highest levels of quality and safety.

The cold source is designed to circulate supercritical hydrogen pressurized to 15 bar absolute at temperatures between 18-20 K at a rate of approximately one liter per second through a moderator inserted inside HB-4. The hydrogen cools neutrons emitted from the reactor causing enhanced production of 4-12 Å neutrons. The neutrons are conveyed outside of the beam tube using wave guides which terminate in a dedicated cold neutron guide hall. The majority of the hydrogen components are designed for 19 bar abs. The hydrogen storage vessel and the relief accumulation vessel are the sole components designed to a lower pressure of 6 bar abs.

The heart of the cold source is the aluminum moderator. It is constructed of 6061-T6 aluminum and is designed for 100 Mw operation with a 20% contingency. The lifetime of the moderator vessel is unknown due to the intense radiation environment inside the beam tube near the reactor core. However, it along with the beam tube will be replaced each beryllium outage. It is anticipated the moderator will see a heat load of between 2.5 kw and 3 kw.

The cold source must be in one of two modes of operation for the reactor to operate. Production Mode is the desired mode where 4-12 Å neutrons are being produced. Standby Mode is a mode where the cold source moderator is indirectly cooled using liquid nitrogen. Standby Mode has two sub-modes; standby compressor mode and standby circulator mode. Standby compressor mode uses a refrigerator compressor, inventory control features, and the normal cold box flow to cool the hydrogen/helium heat exchanger to 77 K. Standby circulator mode uses a dedicated circulator inside the helium transfer module to circulate 77 K helium in a shortened loop inside the refrigerator cold box, helium transfer module, and heat exchanger module.

The hydrogen system is designed as a closed system. An adequate inventory of hydrogen is added to the hydrogen storage vessel to allow the loop to be cooled to Production Mode temperatures. During periods of non-operation, the majority of the hydrogen inventory is returned to the hydrogen storage vessel for re-use. Discharges from relief devices in the hydrogen loop are captured in a relief accumulation vessel for controlled release to the environment. All relief lines which could receive hydrogen are inerted.

Cold source cryogenic systems are insulated by vacuum at 10^{-6} torr or better. The vacuum spaces around hydrogen lines are continually monitored by residual gas analyzers (RGAs) to evaluate impurities in the vacuum spaces. Cryogenic hydrogen systems and selected areas of ambient temperature hydrogen systems are provided with slightly pressurized blankets of helium to further preclude impurities from getting into a hydrogen system. Hydrogen components on the 7977A pad are not blanketed.

Heat deposited in the hydrogen systems is removed by a standard industrial helium refrigerator rated at 3.5 kw heat removal capability at 20 K return. The refrigerator for the cold source is a helium expansion engine design. It utilizes up to five compressors to circulate helium through a series of stacked regenerative heat exchangers to supply up to four expansion engines. The expansion engines take in high pressure helium at ~ 235 psig and discharge it at ~ 1 psig. The gas performs work on the engine by forcing pistons to reciprocate inside of cylinders, rotating a crankshaft. This work cools the gas. Each expansion engine consists of two pistons. The refrigerator utilizes liquid nitrogen as a pre-cooler to bring the inlet helium down to 77 K. The regenerative heat exchangers exchange heat between the in-coming and exiting helium flows to maximize the efficiency of the refrigerator. When the heat exchangers are balanced, all the unjacketed helium piping outside of the cold boxes remains at ambient temperatures. The heat exchangers, engines, and other cryogenic systems are contained inside of cold boxes, which are maintained under high vacuum.

A design goal is to preclude the hydrogen moderator from exceeding 150 ˚C, as aluminum 6061-T6 starts losing its temper at that temperature. To ensure this limit is not exceeded, the reactor heat source must be shut off, or scrammed, during low pressure events in the hydrogen loop, high temperature events in the hydrogen loop, and low flow events in the hydrogen loop. These scrams operate on the two out of three coincidence principle. Each scram has three sensors except for the flow sensor. The flow sensor has one venturi feeding three separate dP cells.

A final means of protection for the moderator is to flood the vacuum space around the moderator with helium. This provides a path for conduction of decay heat from the moderator to the beam tube. The beam tube conducts the heat to the surrounding cooling water. Helium flooding should be used only as a last resort, as the helium will take several weeks to pump out to a level where the vacuum module's RGA can detect a helium leak into the vacuum space adequately.

Buildings and Infra-structure

The cold source is primarily located in buildings 7977, pad 7977A, and building 7900. Space to locate Building 7977 was excavated from an existing earthen bank, creating a sharp change in elevation of approximately 20'. A soil nail wall was installed to provide support for the earth. The wall is L-shaped and runs from the east wall of HFIR approximately 91' and turns at a 90° angle southward for approximately 62' to laterally define the space required for the building (approximately 153' total wall length). The 20' tall wall consists of up to 4 tiers of soil, each epoxy-coated nail was placed in a 8" diameter hole and grouted in place. The length of the nails varies but may be up to 16'. The concrete wall is nominally 8" thick and covers the head of each nail. The area behind the wall is drained with 2" weep drains on 10' centers; the area below the wall is drained with a 4" PVC pipe placed on a 1% sloping grade. The drains empty into an existing below-grade drain tile. The wall is designed with a safety factor of 1.5. For the soil nail wall to remain viable, the earth surrounding the soil nails must remain undisturbed. A fence is installed on top of the wall for fall protection purposes.

Building 7977 is located three feet immediately east of building 7900, at the southeast corner, adjacent to and sixteen feet north of the Electrical Building (Building 7901). It is a single story, metal frame building of 2,584 ft^2 located on a 76' x 34' x 6" thick concrete pad. The west end of the pad is poured on top of a vital electrical duct bank for the HFIR. To eliminate potential load transferal problems with the duct bank, this area of the 7977 pad is engineered such that none of the pad's load is transferred to the duct bank. To carry the building loads, a 30' long steel re-enforced concrete beam is buried ~ 30" deep and supported by vertical concrete piers installed adjacent to the duct bank. Copper sheathing is installed immediately above the duct bank and grounded to prevent electromagnetic fields causing problems with sensitive equipment mounted on the pad. The building walls are a structural frame with interlocking metal panels supporting Z purlins. The roof consists of Z and C purlins covered with interlocking metal panels supported by steel beams. The building is separated into three areas by gypsum wall boards and metal doors. These areas are called the cold box room, the compressor room, and the hydrogen equipment area. The walls between the cold box room and the hydrogen equipment area are two-hour fire rated. The wall between the cold box room and building 7900 is one-hour fire rated. A window between the cold box room and the hydrogen equipment area is rated at two hours. The cold box room and the compressor room each have a south facing 2'6" W x 2'8" H window. A helium storage tank, a 13.8 KV dry electrical transformer, and a 75 KW diesel generator are located on the pad on the east end of the building.

The cold box room is an irregular L-shaped region approximately 900 ft^2 in area (internal measurements) and 15,266 ft^3 in volume. It is heated with a conventional 3.5 ton heat pump backed up by a forced convection steam heater; during periods of high ambient temperature it is cooled by the heat pump and may be ventilated with an exhaust fan. The room is insulated with R-11 insulation in the walls and R-19 insulation in the ceiling. The room has one personnel door communicating with the outside, one personnel door communicating with the hydrogen equipment area, one personnel door communicating with the compressor room, and a 10' x 13' roll-up door. The roof has a 5' x 5' translucent roof panel positioned directly above the heat exchanger pod. The panel is removable allowing an outside crane entry to remove the pod cover for maintenance. The room houses the heat exchanger pod and the engine pod of the refrigerator; the helium inventory control panel; the helium transfer module; helium addition station(s) and helium gas bottles; LN transfer lines, gaseous helium transfer lines, instrument air, and cooling water lines; control stations for the refrigerator, hydrogen loop, and ancillary support systems; and several computers and supporting office equipment. Due to the nature of the equipment in the cold box room, the room has the potential for release of liquid nitrogen or gaseous helium in case of an accident with the refrigerator and refrigerator support systems. It is equipped with an oxygen deficiency detector (OD^2) alarm system to warn of oxygen depletion. This system has an oxygen sensor mounted ~8.5” from the floor, which continually monitors the atmosphere, and displays the room air’s percentage of oxygen on a unit on the east side of the room. Normal oxygen levels at the HFIR site are 20.8%. The OD^2 unit provides a warning at 20% oxygen, it alarms at 19.5% oxygen. The alarm causes a beacon in the room to flash, an alarm buzzer and light to activate on the display unit, an outside beacon to rotate and flash, and a dedicated room exhaust fan to start. An autodialer system communicates the alarm to the HFIR control room or the LSS office. The room exhaust fan is a ¼ HP, 20” shuttered fan which exhausts 2920 cfm of room air. The fan is thermostatically controlled; however, an OD^2 alarm will start the fan independently of the thermostat. Fresh air is drawn into the room near the floor on the northeast side of the room. Fresh air is ducted from the north-east end of the building; the inlet air is drawn in approximately 15’ above ground level and is filtered prior to entering the building. The air inlet point is > 65’ from the hydrogen pump module in the hydrogen equipment area and > 81’ from the hydrogen storage vessel at building 7977A. An OD^2 alarm will lock in causing the display unit to continually emit an audible signal, the room’s beacon to rotate, and the fan to remain ON. The alarm must be reset at a control station.

The compressor room is a rectangular area of approximately 1216 ft^2 (internal measurements) and 20,670 ft^3 in volume. It is heated with a forced convection steam heater; during summer-like conditions it is ventilated with an exhaust fan. The room is un-insulated. The room has two personnel doors communicating with the outside, one personnel door communicating with the cold box room, and one 8’ x 10’ roll-up door. The roof features a 5’ x 5’ translucent removable roof panel for maintenance support. The room houses 5 vertical screw helium compressors and transfer lines; 3 instrument air compressors, an air dryer, and transfer lines; a motor control center (MCC); a demineralized water cooling system and demineralizer; process water cooling equipment; a nitrogen gas addition station, two CPTherm/water cooling water systems (chilled water), a flammable storage locker; and miscellaneous support equipment. The compressor room has a potential for release of helium. It is equipped with an OD^2 system which operates in a similar manner to the OD^2 system in the cold box room. The oxygen sensor is located in the overhead of the east end of the room as helium is lighter than normal air and will rise. The display is located on the east wall of the room, an alarm beacon is located immediately above the center compressor. The fan in the compressor room is a 1/3 HP, 24” shuttered fan; it exhausts 5,520 cfm of room air. During non-alarm conditions, the fan is controlled by a thermostat immediately below the OD^2 display. An alarm overrides the thermostat control function. The alarm performs functions similar to the cold box room alarm. Air intake into the compressor room enters approximately 15’ above the center compressor. A portable OD^2 monitor is kept in a storage locker in the building for use in case one of the installed OD^2 monitors fails.

The hydrogen equipment area is a 286 ft^2 area adjacent to the cold box room. It has a volume of approximately 4,928 ft^3. The HEA has personnel doors on the north and south ends. It has an equipment door on the south side. The south and west walls are demountable fire walls rated for one hour. The HEA is accessed by personnel doors from the south side and communicates with the cold box room through a personnel door which cannot be locked. The walls between the hydrogen equipment area and the cold box room are fire rated at 2 hours. The HEA contains six sprinkler heads. It is heated by steam heaters. The HEA has a raised cupola which is ventilated by redundant fans. Inlet air to these fans is drawn from door vents on the south end. The fans run at low speed whenever hydrogen is present in cold source equipment. They switch to high speed upon detection of hydrogen in the HEA or the duct, which would be indicative of a leak. The east wall of the raised gable contains dampers which open at pre-set delta pressures. They are sized to comply with code requirements for special hydrogen rooms.

The HEA contains a two-ton manual powered hoist for moving hydrogen equipment in the hydrogen equipment area. The area houses most of the active components of the hydrogen loop, including the pump module, hydrogen-helium heat exchanger, purge module, the hydrogen equipment area vacuum module, and the gas handling module. The hydrogen lines in each of these modules are blanketed by helium and components containing cryogenic hydrogen have an insulating vacuum layer around them. The crane support frame runs from the south wall of the cold box room to the edge of building 7901. As mentioned previously, a two-ton manual crane is installed inside the HEA. A six-ton manual crane is installed outside the HEA. This crane is utilized to move equipment off of the load-limited duct bank.

The pad for the hydrogen equipment area is also load limited to protect the vital electrical duct bank underneath it. The pump module is supported by beams installed between a support beam adjacent to the cold box room wall and building 7900. The majority of the crane frame and all the remaining modules are supported off the hydrogen equipment area pad. These loads have been analyzed and found to be within design constraints for the pad.

Building 7977 is serviced with four telephone lines and one 10baseT data connection. Two telephone lines are utilized for standard communications, the third is dedicated to communications with the liquid nitrogen tank, and the fourth is dedicated for use by an autodialer in case of building alarms. The LN tank level is continuously monitored and evaluated by the control system. Upon indication of rapid loss of level, the computer activates the autodialer, which calls preset numbers to annunciate the problem. The alarm must be acknowledged by pressing the “9” button on a telephone to secure the autodialer, otherwise it continues calling preset numbers until the alarm is acknowledged. Alarms are generated at tank level decreases of > 0.1 in/min averaged over 5 minutes, > 0.3 in/min averaged over 1 minute, > 4 in/minute averaged over 1 minute, and > 25 in/min averaged over 30 seconds. The control computer communicates with the hydrogen equipment, the refrigerator, and other support equipment. A separate server communicates with the control system and the ORNL server. Other computers are utilized to monitor process equipment as needed.

The fire suppression system for building 7977 is a dry pipe sprinkler. The ½ inch upright sprinkler heads are rated at 155°F; sprinkler heads near heaters are rated at 212°F. The system is supplied from a 6-inch riser in building 7901. A dedicated air compressor keeps the dry pipe pressurized to approximately 100 psig. The air compressor is powered from building 7977, but may be powered from a building 7901 electrical source during periods of switch gear maintenance. Two fire extinguishers are located in building 7977 and there are fire alarms at each normal exit from the building. The cold box room and compressor rooms have self-contained battery-operated emergency lights which energize upon loss of normal power. The emergency exit lights also have self-contained batteries to provide illumination in case of normal power loss.

System Descriptions

The cold source systems are separated into sub-systems and briefly described in the following sections. Comprehensive descriptions of the equipment are available from the Cold Source Experiment Operations Manual and systems manuals.

1. Hydrogen Systems

The hydrogen systems include the beam tube internals, transfer lines, pump module, gas handling module, heat exchanger module, hydrogen storage vessel, hydrogen compressor, and purge module. All of the modules except for the hydrogen compressor and hydrogen storage vessel are located in the hydrogen equipment area. Each module is a pressure vessel rated for 2.5 bar abs; several modules are vessels within a vessel.

Beam Tube Internals

The HB-4 beam tube is an aluminum tube a minimum of four inches in diameter and ~ sixteen feet long cooled by reactor coolant circulating on its external periphery. The beam tube is a boundary for the reactor primary coolant system. The tube rests immediately adjacent to the outer fuel element inside the permanent beryllium reflector. The beam tube contains the cold source moderator vessel, transfer lines, and vacuum tube. It is roughly divided into two sections, a front and rear section. The front section contains the moderator and two hydrogen transfer lines which connect to transfer line 1 at an aluminum window. The front section is inside a vacuum tube which is pumped by the beam room vacuum module. The exterior of the vacuum tube is grooved and the space between the vacuum tube and the beam tube is filled with helium. Dedicated helium supply and return lines communicate with this space from a manifold in the beam room. The relief valve for this helium area relieves to the pool. The relief valve for the vacuum area relieves to a cold source stack. The rear section of the beam tube contains transfer line 1. Two aluminum windows are used to separate the front section from the rear section of the beam tube; one aluminum window is used to separate the rear section of the beam tube from the beam room. The space between the two front windows is inerted with helium supplied by transfer line 1. The rear section of the beam tube contains the collimator; this section is inerted with helium supplied and controlled from HFIR helium supplies. This area may also be flooded with pool water for shielding purposes. The relief valve for this area relieves to the gaseous waste system.

The vacuum tube inside the beam tube provides an insulating environment for the cryogenic hydrogen transfer lines. In case of loss of cooling accidents to the moderator, the internal cavity of the vacuum tube has the capability of being pressurized with helium. Helium will transfer activation heat from the moderator to the primary coolant through the vacuum tube wall and the beam tube wall. This method of cooling is controlled by the cold source and would only be used as a last resort to prevent damage to the moderator vessel.

The moderator is a hydrogen-filled and cooled aluminum 6061 vessel which interacts with neutrons from the core and slows them to cryogenic wavelengths. The moderator is designed for 19 bar abs. pressure. Hydrogen at 18-20 K and a nominal flow rate of 1 liter/sec enters on the horizontal plane away from the reactor and exits on the side toward the reactor. Neutrons cooled by the moderator exit through wave guides and are directed to experiments up to several hundred feet away.

Transfer Lines

Stainless steel transfer lines are used to provide flow paths for hydrogen to be circulated from the HEA area to the moderator and back. There are three transfer lines numbered sequentially. All transfer lines provide vacuum insulation and helium boundary layers. Transfer line one is inside the beam tube. It penetrates the back window and extends through the two front windows. Transfer line one consists of five flexible lines nested inside each other. The inner line is hydrogen supply, the second line is vacuum, the third line is hydrogen return, the fourth line is vacuum, and the outer fifth line is helium. The flexible lines allow shrinkage and expansion associated with temperature changes of 250 K or greater to occur without damage to the lines. Hydrogen flows from transfer line one through a coil arrangement, through stainless to aluminum transition joints, and then to the moderator through smooth walled aluminum lines. Two stainless to aluminum transition pieces are welded into the outer tubes of transfer line section one to change the lines from stainless to aluminum to weld into the aluminum windows. Super-insulation is not used in this line due to high radiation levels. Spacer stand-offs between the lines to keep them from being in direct contact are made from titanium. Transfer line section two routes the hydrogen supply, hydrogen return, vacuum, and helium underneath the beam tube shutter. With use of a special invar socket, it connects to transfer line one at the beam tube back window and to transfer line 3 at the transition assembly. Supply and return lines in transfer line 2 in the vicinity of the shutter are in a vacuum but are not separated by a vacuum line as in transfer line 1. Hydrogen supply and return are in separate lines inside a vacuum environment which is inside a helium line. After transitioning under the shutter, transfer line 2 becomes a nested five line up to the transition assembly. Transfer line 2 does not contain super-insulation; however, the inside of the vacuum line and outside of the hydrogen line are polished to minimize heat gain. Transfer line 3 consists of a pair of lines originating from the pump module in the HEA and connecting to transfer line two at the transition assembly. Each transfer line 3 consists of four nested lines. Each inner line is hydrogen, the second line is vacuum without super-insulation, the third line is vacuum wrapped with super-insulation, and the fourth line is helium. Standoffs separating these inner lines are made from the vendor's standard materials. During its transit through building 7900, transfer line 3 is inserted inside a large conduit. This is done to add a further barrier to prevent hydrogen leakage into the building. The conduit communicates with the outside and is sealed inside building 7900.

Transition Assembly

The transition assembly is located adjacent to the shutter and provides a vacuum and inert environment for coupling transfer line 2 to transfer line 3.

Pump Module

The pump module provides an inert environment for location of the variable speed circulators (VSCs); pressurizer; flow, temperature and pressure scram sensors; circulator control differential pressure sensors; control system pressure and temperature sensors; inlet and exit valves for the circulators; a bypass line with bypass isolation valve; hydrogen lines connecting the various components; and gaseous valve actuation controls and lines. The pump module consists of two boundary layers. The outer layer of the module is inerted with helium gas. Gas operated valves in this module operate with helium gas; helium resulting from valve operation is discharged immediately outside the pump module in the hydrogen equipment area.

The VSCs are one-of-a-kind variable speed circulators developed for ORNL by Barber-Nichols and Revolve. They rotate at speeds varying from 15,800 RPM up to 58,000 rpm using electromagnetic bearings. The circulators have separate helium gas cooling which includes a fan-forced cooling loop that exchanges heat with the chilled water cooling system. The inner layer of the module is under high vacuum from the HEA vacuum module.

The pump module pressurizer warms hydrogen being discharged and cools hydrogen being added to the system. Attached to the outer surface of the pressurizer wall are seven silicon diodes that are used during testing to verify temperature profiles and confirm the capabilities of the pressurizer. They are not required to operate after testing.

The pump module is fabricated from stainless steel and weighs ~10,800 pounds. It is located on a stainless steel support structure. The entire module/support structure rests on rails allowing movement in the east-west direction for coupling or uncoupling of the main hydrogen transfer line on the west side of the module. The rails are secured to the load bearing floor section of the hydrogen equipment area pad and the HFIR building to preclude load transfer to the pad above the duct bank. During normal operation, the module will be secured to the hydrogen equipment area pad to prevent movement. The heat exchanger module is flanged directly to the south side of the pump module and is supported from the pump module support structure.

Gas Handling Module

The gas handling module provides an inert environment for location of components performing the feed and bleed function, as well as the location for obtaining the hydrogen sampling gas. These components consist of the hydrogen transfer lines, motor-operated valves, gas-operated valves, a pressure sensor, solenoid valves, and safety relief valves. The gas handling module supplies one layer of helium boundary gas. The helium blanket is common to the pump module outer layer and the heat exchanger module outer layer. A redundant relief valve is included on the gas handling module as the relief pathway from this module to the pump module relief valve is tortuous. Gas operated valves in this module use helium. Valve operation exhaust helium gas is discharged to the hydrogen equipment area immediately adjacent to the gas handling module. The gas handling module requires cooling from the chilled water cooling system to remove heat from the electrical valve operators. The gas handling module weighs approximately 1500 pounds and is mounted on the equipment support platform on the north side of the hydrogen equipment area.

Heat Exchanger Module

The heat exchanger module provides an inert environment for the helium to hydrogen heat exchanger and a temperature sensor in the helium supply line. The module has two boundary layers. The outer helium layer is common to the pump module and the gas handling module. The inner high vacuum is supplied by the hydrogen equipment area vacuum system.

The heat exchanger module is flanged directly to the pump module and is securely mounted on the pump module support structure. It does not require ancillary cooling.

Purge Module

The purge module is utilized to purge the hydrogen loop prior to adding hydrogen to it. It provides an inert environment for location of the purge vacuum roughing pump, control valves, thermal relief valves, and a vacuum sensor. The module provides one layer of helium boundary. Gas operated valves in this module operate with helium; valve operation exhaust helium gas is discharged to the hydrogen equipment area immediately adjacent to the purge module. Equipment in the purge module evacuates the entire hydrogen loop, but may be configured to purge the area between each circulator's inlet and exit valves. It also allows the hydrogen loop to be back-filled with helium as part of the purge cycle.

The purge module weighs approximately 1500 pounds and is bolted to the floor of the hydrogen equipment area southeast of the pump module. The module requires cooling from the chilled water cooling system to remove heat generated by the vacuum roughing pump and the solenoid valves.

Hydrogen Compressor

The hydrogen compressor raises hydrogen pressure from the hydrogen storage vessel minimum pressure of ~1.0 psig to the feed pressure of 16 bar abs. It is located on pad 7977A adjacent to the hydrogen storage vessel. The hydrogen pump, valving, and the hydrogen feed vessel are all co-located. The hydrogen pump is a positive displacement pump. Reciprocating pistons convert mechanical energy to work flow of the hydrogen. It uses a triple diaphragm to ensure the hydrogen is isolated from the hydraulic fluid and the pump's lubricated parts. The hydrogen pump requires cooling from the chilled water cooling system to remove heat from each of its two heads, from the inlet gas, the inter-stage gas, the exit gas, and finally the oil. Each has a dedicated cooler.

The hydrogen pump may be configured to discharge from the hydrogen storage vessel to the gas handling module or from the gas handling module to the hydrogen storage vessel. This feature allows the pump to be utilized to pump the majority of the hydrogen out of the loop prior to maintenance periods, which minimizes discharges of hydrogen to the stack.

The feed vessel is immediately downstream of the hydrogen compressor and stores ~200 liters of hydrogen gas at 16 bar abs for use as make up to the hydrogen loop.

Test Assembly

The test assembly (dummy load) is a 4.5 kw electric heater (Note: design is not final) located between transfer line 3 and the transition assembly. It is instrumented with temperature elements and a flow element. The heater is on the return from the moderator flow side. The dummy load is for use during testing only. It will not be installed when the beam tube is installed inside the reactor.

2. Cryogenic Helium Systems

The cryogenic helium systems consist of the refrigerator and the helium transfer module.

Refrigerator

The refrigerator is a standard industrial unit used to cool helium which removes heat from the hydrogen loop. It was manufactured by Process Systems International, is located in building 7977, and rated at a heat removal of 3.5 kilowatts at 20 K return temperature. The refrigerator has five compressors to compress the helium gas and deliver it to four expansion engines. The helium expands against pistons in the engines thereby doing work which results in cooling of the gas. The refrigerator uses liquid nitrogen to pre-cool the helium to approximately 77 K. The compressors require cooling from the demineralized water cooling system to remove heat of compression from the gas and to cool the compressor oil. The refrigerator has a dual train vacuum system; each train has a roughing pump, a turbo-molecular pump, valves, and sensors. The vacuum systems maintain a vacuum level better than 1E-6 torr in the cold boxes during normal operations.

Three relief devices on the refrigerator are connected to the relief system. These are on the load and return side of the refrigerator and would actuate if there were a leak in the hydrogen to helium heat exchanger. Since the hydrogen loop operates at higher pressure than the helium loop, hydrogen would migrate into the refrigerator under that scenario. The relief valves discharge to a stack.

Hydrogen sensors are installed in the inventory control panel of the helium loop to monitor for leaks from the heat exchanger.

A 2,500 gallon helium storage tank is utilized to store helium when the refrigerator is not in operation and to supply helium during refrigerator operation. An inventory control system automatically adds and removes gas to the system as required. Ultra high purity (UHP) helium gas is supplied through the inventory control panel from gas bottles when required. Liquid nitrogen (LN^2) is supplied from an 11,000 gallon tank located approximately 150 feet northeast of building 7977 on pad 7977A. LN^2 evaporates as it absorbs heat from the helium gas; the gaseous nitrogen is discharged immediately above the roof line on the southwest side of building 7977.

Helium Transfer Module

The helium transfer module is utilized to provide backup flow capability during periods when the refrigerator is unavailable. During normal operation of the refrigerator, it supplies electrical resistance heating both to mimic reactor heat to minimize transients the refrigerator is exposed to and to provide for hydrogen temperature control. It provides a vacuum environment for a BNCP-19C helium circulator, the load compensating heater, the trim heater, valving, and sensors. The helium transfer module vacuum is extended from the refrigerator vacuum system. The vacuum also includes the goal post transfer lines connecting the helium transfer module to the refrigerator. The helium circulator is utilized mainly during standby circulator mode. When it is operating, the helium circulator requires cooling from the demin water cooling system to remove heat from the motor.

The BNCP-19C is manufactured by Barber-Nichols. It has mechanical bearings and is designed to operate at 12,000 RPM and provide 5.9 L/sec helium flow at 80 K against a head of 280 m with an inlet pressure of 5 bar abs. The circulator takes ~ 30 seconds to ramp up to full speed during startup. During standby circulator mode, helium pressure in a shortened flow loop is raised to 6 bar abs by dedicated gas bottles.

Two relief devices in the helium transfer module are connected to the relief system. The helium transfer module weighs ~ 2000 lbs and is mounted on the floor west of the refrigerator cold box in building 7977.

3. Gas Stations

The cold source uses several common industrial gases during operation. As a result, the possibility of the wrong gas being inadvertently connected to a module or process has received significant design attention. To preclude this type of accident; helium, nitrogen, and hydrogen gas bottles will be stored in separate locations. Connections to modules will be color coded and engineered to require unique fittings which are peculiar to only one type of gas. Modules will be clearly labeled as to the type of cover gas contained in them and also color coded using standard industrial color codes (with the exception of nitrogen). The colors are as follows: helium-blue, hydrogen-yellow, nitrogen-orange (Note: the standard industrial color for inert gases such as nitrogen is blue).

Helium Gas

Helium gas at a nominal pressure of 1 to 4 psig provides an inert boundary for several of the hydrogen systems; as an activation gas for remotely operated valves located within a helium environment, such as modules; and as a refrigerant for the refrigerator. Helium is used to purge hydrogen lines, prior to charging them with hydrogen. In the relief system, helium is used to inert the discharge side of several relief devices, to inert the relief accumulation vessel, and to inert several stacks. Helium may be utilized to flood the beam tube as a cooling measure. A helium bottle rack is located close to the entrance to the hydrogen equipment area inside the cold box room in building 7977. A separate helium bottle rack to charge the refrigerator system is located on the north wall of the cold box room. This bottle rack will have a dedicated bottle to charge the sections of the refrigerator to 6 bar abs that are needed during standby circulator mode. A third bottle rack will be located in the stack area to inert the vent system and purge lines. A fourth bottle rack will be located in the beam room to be used to flood the vacuum space surrounding the moderator.

Nitrogen Gas

Nitrogen gas provides an inert boundary for the vacuum modules. These modules must use nitrogen as their electronics operate at voltages which arc in helium. Nitrogen gas is used as an activation gas for valves located in these modules. Discharge gas from operation of the valve remains inside the module. The valves do not operate very frequently, so internal pressure of the module should not vary much due to this feature. The nitrogen gas bottle station is located in the compressor room in building 7977.

Hydrogen Gas

The hydrogen bottle charging station is in the stack area. Hydrogen bottles will be strictly controlled and will only be connected to the system during charging periods. During all other periods, the bottles will be secured in a covered area.

Liquid Nitrogen

Liquid nitrogen provides pre-cooling for the first stage of the refrigerator system. It also provides primary cooling when the cold source is in standby circulator mode or standby compressor mode. LN^2 is supplied from an 11,000 gallon tank on pad 7977A. The tank is maintained at 20 psig by a regulator and continually blows off gaseous nitrogen through the regulator. The tank is periodically refilled by a vendor. It has dedicated telemetry for readout indications on level and pressure.

4. Vacuum systems

All cryogenic systems including the hydrogen transfer lines, helium transfer lines, and the refrigerator cold boxes are vacuum insulated. Dedicated vacuum modules, designated as the hydrogen equipment area vacuum module and the beam room vacuum module, maintain 10^{-6} torr for the vacuum spaces surrounding cryogenic hydrogen lines. The vacuum modules are identical and interchangeable. Each vacuum module has a residual gas analyzer inside it which continually monitors for elements with a mass peak of 2, 4, 28, and 32 (hydrogen, helium, nitrogen, and oxygen). Detection of these mass peaks at greater than designated thresholds will initiate alarms from the module and the control system. Each vacuum module has a dedicated computer for in-depth analysis of the gas being pumped. Selected controls and readouts are transmitted to the main cold source control systems for analysis and control.

The refrigerator cold box has its own dedicated refrigerator vacuum system. The helium transfer module, the goal post transfer lines connecting the helium transfer module to the cold box, and the transfer line connecting the helium transfer module to the heat exchanger module are evacuated by the refrigerator vacuum system.

The purge module vacuum pump is a roughing pump used to purge the hydrogen lines prior to adding hydrogen to them. It is the same model of pump as the roughing pump on the refrigerator and the roughing pump in each vacuum module. This allows one spare pump to be used in three different applications.

A portable vacuum pump will be used for initial purging of the hydrogen storage vessel, the relief accumulation vessel, and other cold source components. It will also be used in gas filling operations to evacuate interconnecting piping. The pump will discharge at its location or to a stack. Other portable vacuum pumps will be utilized as required.

5. Relief/Vent Systems (Note: Design is not final)

The relief system includes the relief stacks, the relief accumulation vessel, and interconnecting transfer lines. The relief systems provide for safe removal and/or collection of hydrogen gas in the event of a problem. The system is divided into three main sub-systems. A relief accumulation vessel collects discharges from the high pressure hydrogen loop and the hydrogen storage vessel. The accumulation vessel allows relief device discharges to be collected and discharged in a controlled manner. Relief stacks are the discharge path for most of the relief devices on modules, five helium relief devices, the circulator enclosure relief devices, and the relief accumulation vessel. Where required, separate stacks are provided for the various systems. Each stack will discharge approximately 30 feet above grade, will be grounded, and will have an insulated section to electrically isolate the relief stack from systems discharging into it. This is done to preclude lightning being conducted from the stack to hydrogen loop components. Each relief stack will contain a hydrogen sensor which is monitored by the control system. Detection of hydrogen in excess of a pre-set threshold will initiate an alarm. Multiple oxygen sensors and pressure sensors will be located in the relief system. Readout indications will be displayed by the control system and will also initiate alarms. Undesirable levels of oxygen will be purged from the relief system as required.

The top portion of each stack will contain parallel relief valves which keep the stack pressurized to approximately 1 psig or less. This arrangement will raise the relief point of relief devices which discharge to these spaces by approximately 1 psi. A remote-operated valve may be used to purge each stack as required.

The relief accumulation vessel and piping leading to it will be inerted with helium gas. This will preclude hydrogen discharges from interacting with undesirable gases. It also precludes the inadvertent introduction of undesirable gases during purging of the hydrogen loop. Purging activities will allow relief devices to leak minute quantities of gas backwards through them. Helium does not freeze at temperatures which will cause problems in the hydrogen loop, whereas nitrogen does. Any contaminant in the hydrogen loop is undesirable; however, helium does not cause problems other gases do. The quality of the hydrogen in the loop will be analyzed prior to every cooldown using the RGA in the vacuum module.

A vent manifold system collects discharges from the vacuum module blanket relief valves, the purge pump, and the vacuum pumps and directs the gases to the top of building 7977 for release. The manifold is inerted to slightly above atmospheric pressure with nitrogen.

6. Control Systems

The refrigerator, hydrogen systems, and ancillary support systems are controlled and monitored with a digital control system. The system utilizes RTP hardware and an Intellution graphical user interface (GUI). The RTP system has backup hardware which automatically switches monitoring and control functions in case of a component failure to assure continuity of operations. It is also electrically backed up with a UPS for short term outages with diesel generator back up for long term outages. The control system will monitor and control operations and generate alarms at pre-programmed points. The control system has three cabinets in the cold box room. One cabinet and control station are utilized for the refrigerator and ancillary systems and a second cabinet and control station for the hydrogen and relief/vent manifold systems. The third cabinet is used for the ancillary support PCs. These PCs provide diagnostic capability for the VSCs and the vacuum modules. A scram cabinet will be mounted in the cold source control room inside of building 7900. There are three command and control stations for the cold source; one in the cold box room, one in the cold source control room, and the third in the HFIR control room. All have computers with dedicated monitors which communicate with the RTP hardware station. The command and control stations at the cold source control room and the HFIR control room will not be active during phases A and B/C of testing. All control stations will be active and verified operational prior to proceeding with in-reactor Phase D testing.

The hydrogen loop must be carefully monitored to assure pressures and temperatures remain at desired conditions. This function is handled by the control system. A gas handling system is utilized to control pressure of the hydrogen loop. Primary working fluid gas is added and removed through control valves and a transfer pump at selected setpoints. Pressure control time responses will require setting up and tuning as the testing proceeds. The control system will also control loop temperature and minimize control challenges to refrigerator operation by applying appropriate power to electrical heaters in the helium refrigerant gas. The systems will be set up and tested and the control functions validated during the test programs. Gas operated valves within the modules which provide control for loop functions will be checked for correct operation and sequencing where applicable.

7. Ancillary Systems

Ancillary systems provide essential electrical power, cooling to selected components, and personnel protection. Power may be supplied from one of three redundant systems. Three different water systems are utilized to cool cold source components.

Normal Power

Normal power provides electrical power through the electrical distribution system to cold source components. Normal service is from the 294 feeder through a disconnect switch in building 7901 to transformer # 8 on the east end of the cold source pad. Alternate service is available from the 234 feeder. Selection of the feeder is performed in the HFIR control room.

Back up Power

Back up power provides power to selected cold source components during unavailability of normal power. Power is supplied by a 450 kw diesel generator which automatically starts and picks up load upon loss of normal power within a 10-second time window. Backup power will maintain the cold source in standby compressor mode without adversely affecting the HFIR.

Standby Power

Standby power provides power to selected cold source components in the unlikely event feeders 234, 294 and the backup D/G are unavailable. Power is supplied from a 75 kw diesel generator which monitors the standby power bus and starts when the feeder for that bus has been without power for one minute. Standby power will keep the cold source in Standby Circulator Mode without adversely affecting the HFIR. The redundant D/G was already installed and was kept to minimize risk to the moderator due to loss of power events.

Uninterruptible Power Supply (UPS)

An UPS provides power to transition critical equipment through the time interval between a loss of normal power and a diesel generator becoming available. There is one large UPS in the cold box room which picks up the command and control computers, hydrogen circulators, helium circulator, liquid nitrogen valves, and other components on the standby power panel, panel P-55. Other cold source computers may have their own individual UPS, according to their importance. The UPS is sized to power the standby bus for ~ 15 minutes upon loss of normal power.

Process Water System

Process water flows through the plate heat exchanger and removes heat from the demin water cooling system. It also provides makeup water to the demin water cooling water system. Process water is discharged to the HFIR secondary. The discharge valve is manipulated by cold source personnel; however, close coordination with HFIR is required prior to manipulating the discharge valve. Discharge flow rates to the HFIR secondary vary from 50 gpm to 300 gpm depending upon the heat load

Demineralized Water Cooling System

The demin water cooling system provides cooling flow to the oil coolers and gas coolers on the helium compressors, and the BNCP-19C on the helium transfer module. The system contains two mixed bed demineralizers which maintain the water at optimum pH and conductivity for corrosion prevention. The demin water cooling water system will be on anytime the compressors or BNCP-19C are running. Nominal flow rate is ~ 90 gpm.

CPTherm/Water Cooling System (Chilled Water)

The chilled water system provides cooling flow to systems exposed to ambient temperatures and other critical equipment. The Chilled Water System contains CPTherm to lower the freezing point of the water. Chilled Water System coolant cools the variable speed circulators, vacuum modules, purge module, hydrogen compressor, and gas handling module. The chiller is a commercial split unit which utilizes freon to cool the CPTherm/water solution. Since the Chilled Water System has to be available all the time, it is powered from both diesel generators and redundant components are installed where practical.

Instrument Air

Instrument air is supplied by HFIR's air compressors from a tie-in at the valve pit. A dedicated cold source standby air compressor comes on line if air pressure falls below the control setpoint at the refrigerator. The standby air compressor is powered from the standby electrical bus. A final source of air consisting of bottled nitrogen is placed on line by the control system if the air become unavailable. Instrument air supplies air to vital control valves on the refrigerator including the liquid nitrogen control valve.

Several systems require helium or nitrogen gas to operate control valves. These systems are described in section 3, “Gas Stations”. An additional system to those is a helium pressurizing system which will be required in standby circulator mode. This system pressurizes the helium portions of the circulator loop to 6 bar abs with dedicated helium bottles.

Personnel Protection and Hydrogen Detection Systems

Engineered systems which enhance personnel protection and/or detect release of hydrogen include the oxygen deficiency (OD^2) monitoring system, hydrogen monitors in the refrigerator helium stream, hydrogen air monitors, vent stack discharge hydrogen monitors, and hydrogen equipment area monitors. The OD^2 system monitors the air in the cold box room and compressor room and initiates alarms and other protective functions if oxygen levels of 19.5 % or less are detected.

Cryogenic hydrogen lines are surrounded by vacuum areas which are evacuated by pumps in the vacuum modules. Each vacuum module provides a backup method for confirming hydrogen line integrity. A residual gas analyzer (RGA) in the module continually analyses the amount of hydrogen, helium, nitrogen, and oxygen being pumped by the module and provides alarms at pre-selected thresholds. The RGA’s full output is available from a computer console so that other constituents of the evacuated areas may be evaluated by the cold source staff. Connections are available to allow the vacuum module to be utilized to sample for impurities in the hydrogen gas in the hydrogen loop. A separate analyzer is available to sample for hydrogen in the refrigerator helium gas and to sample for impurities in the cover gas of each module.

The HEA contains hydrogen sensors in the overhead and in the exit air duct. An infrared camera monitors the space for personnel safety. A dedicated computer is set up at the cold box room entrance to the HEA so that personnel entering may monitor the status of the various safety systems prior to entering.

Each relief stack contains a hydrogen sensor to detect the presence of hydrogen in the stack. The sensor will communicate with the control system to alert the staff that a release of hydrogen has occurred. A mass flow meter is installed on the outlet of the hydrogen stack to ensure controlled releases do not exceed safety guidelines. Multiple oxygen sensors and pressure sensors are located in the relief system. Readout indications will be displayed on the control system computers.

The control system continuously monitors the liquid nitrogen tank level and provides alarms for sudden losses. Alarms are set at:

- > 0.1in/min – indicative of abnormally high withdrawal rate;
- > 0.3 in/min – indicative of a line break or small leak at the tank;
- > 4 in/min – indicative of a failure of an appendage on the tank;

- > 25 in/min – indicative of a tank rupture.

Several alarms generated by the control system are routed to an Autodialer. This instrument is pre-programmed with phone numbers of responders for alarm situations. The initiators include OD^2 alarms and liquid nitrogen tank alarms. Other alarms may be programmed in as necessary.

Cold Source Test Configuration

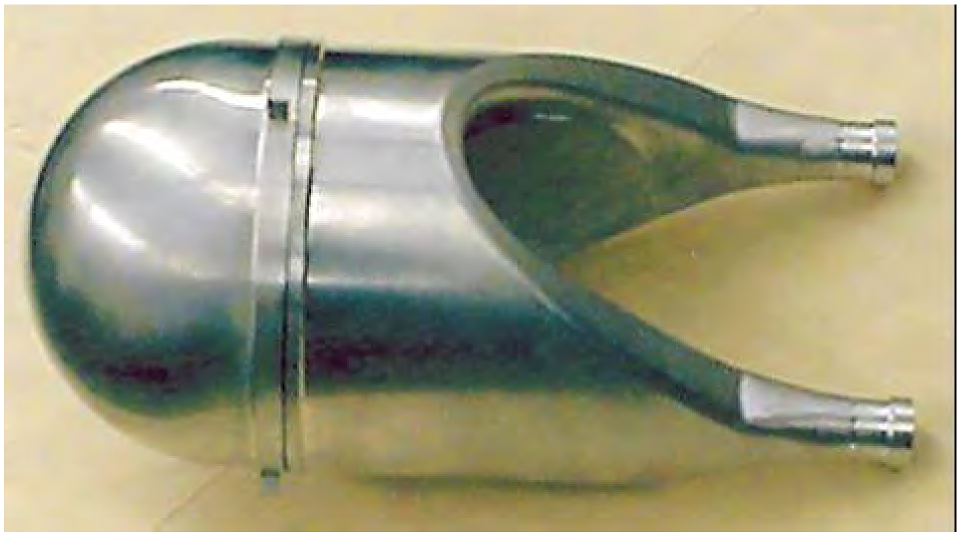

Figure 2.1. Moderator Vessel.

Cold Neutron Guide Hall

HFIR Reactor Building 7900

Cold Source Building

Cold Source rooftop platform. For the Cold Source out-of-reactor test configuration, the hydrogen transfer lines will be routed onto the rooftop platform and terminate at the adjacent hillside platform.

Figure 2.2. Aerial View of Cold Source Building 7977 and surrounding area.

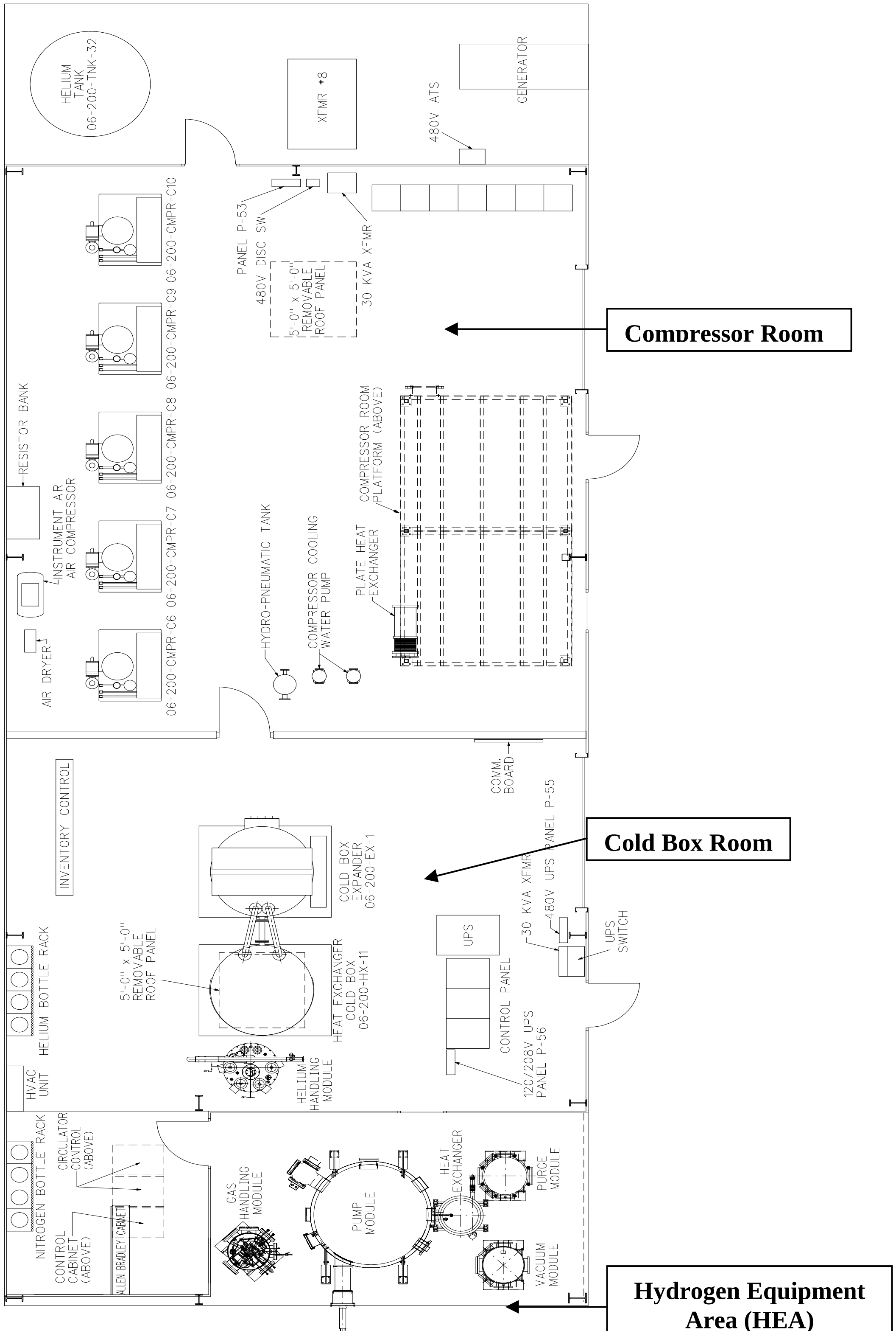

Figure 2.3. Building 7977 Cold Box Room, Compressor Room, and HEA Plan view.

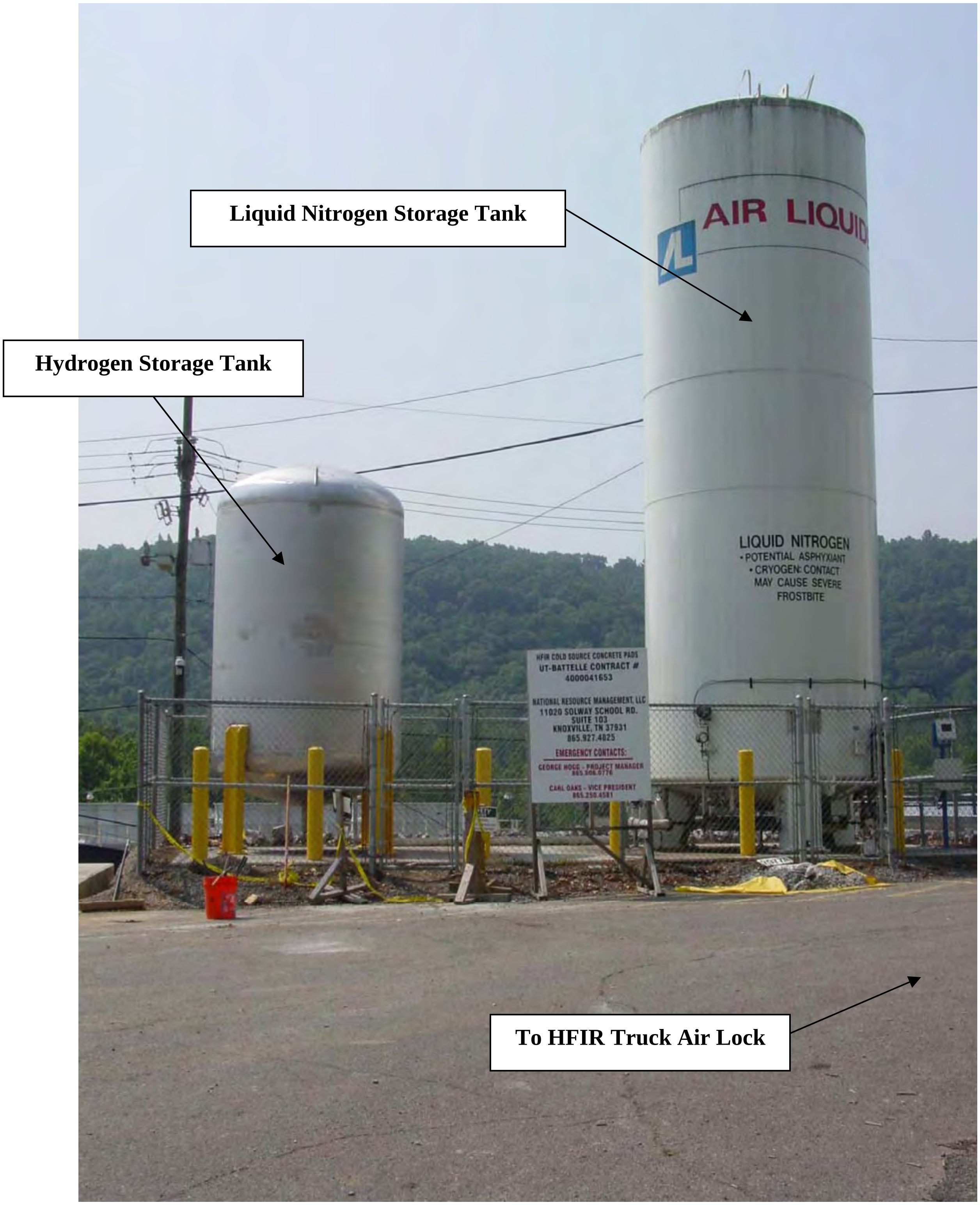

Figure 2.4. Hydrogen and nitrogen storage tanks.

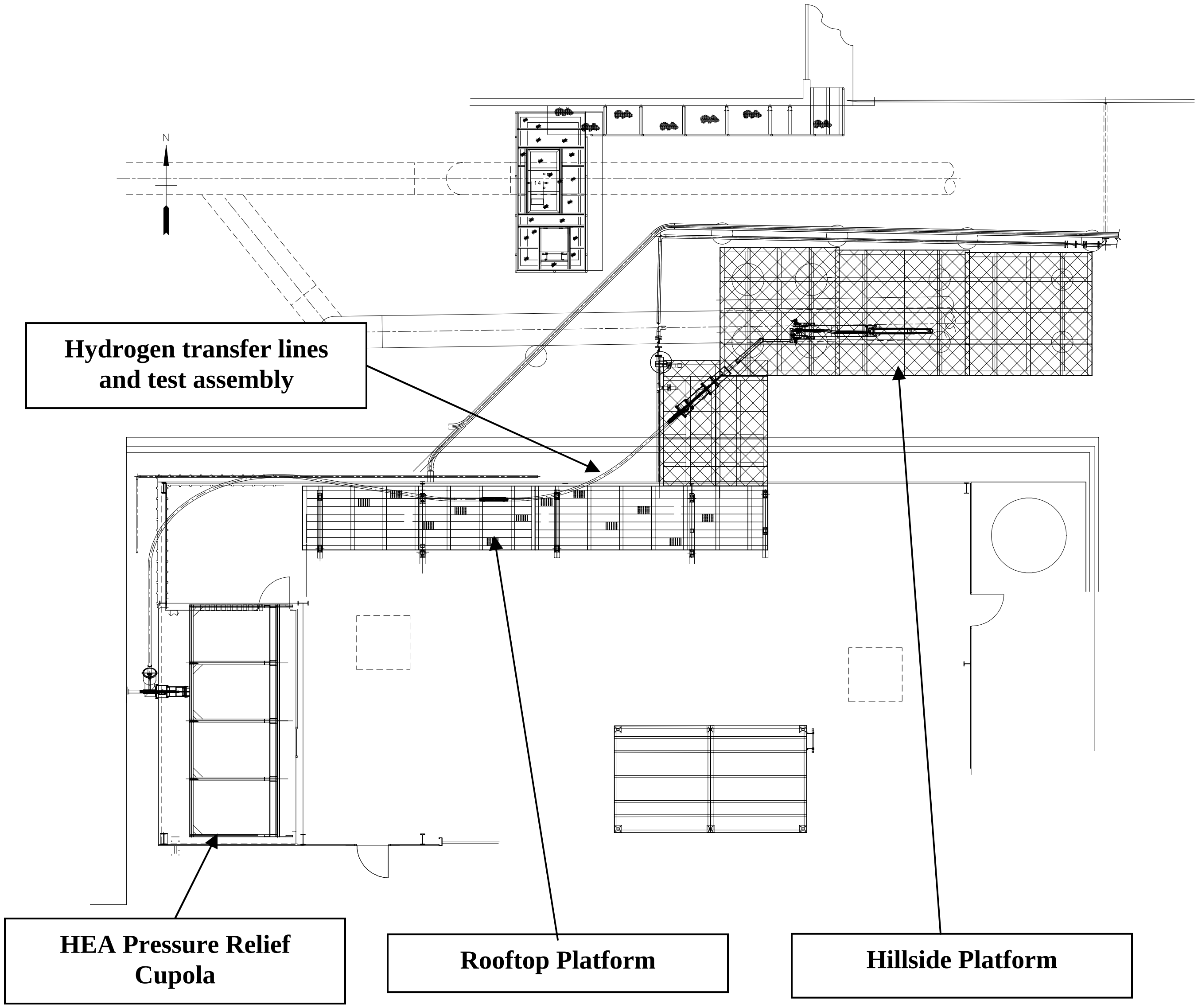

Figure 2.5. Test configuration layout outside HFIR Reactor Building.

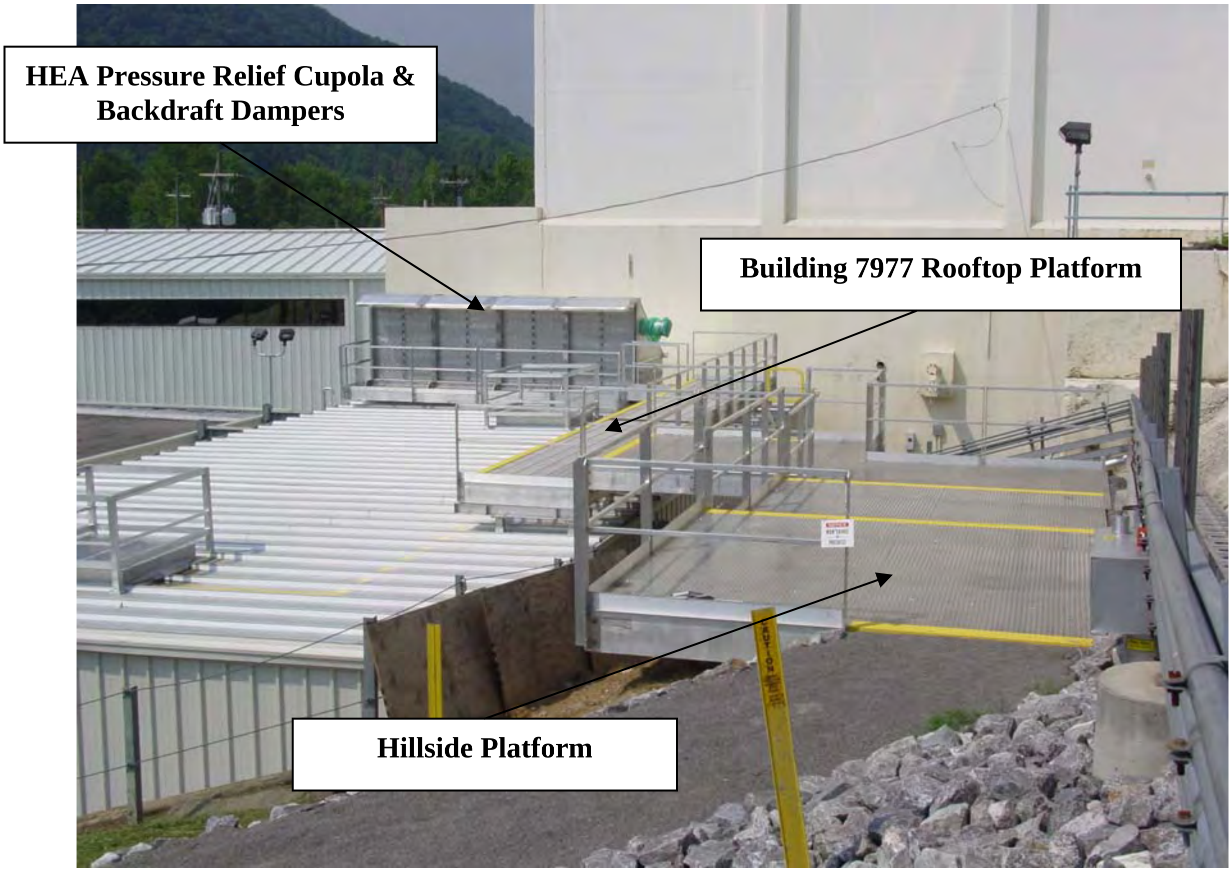

Figure 2.6. Installed Building 7977 rooftop and hillside testing platforms.

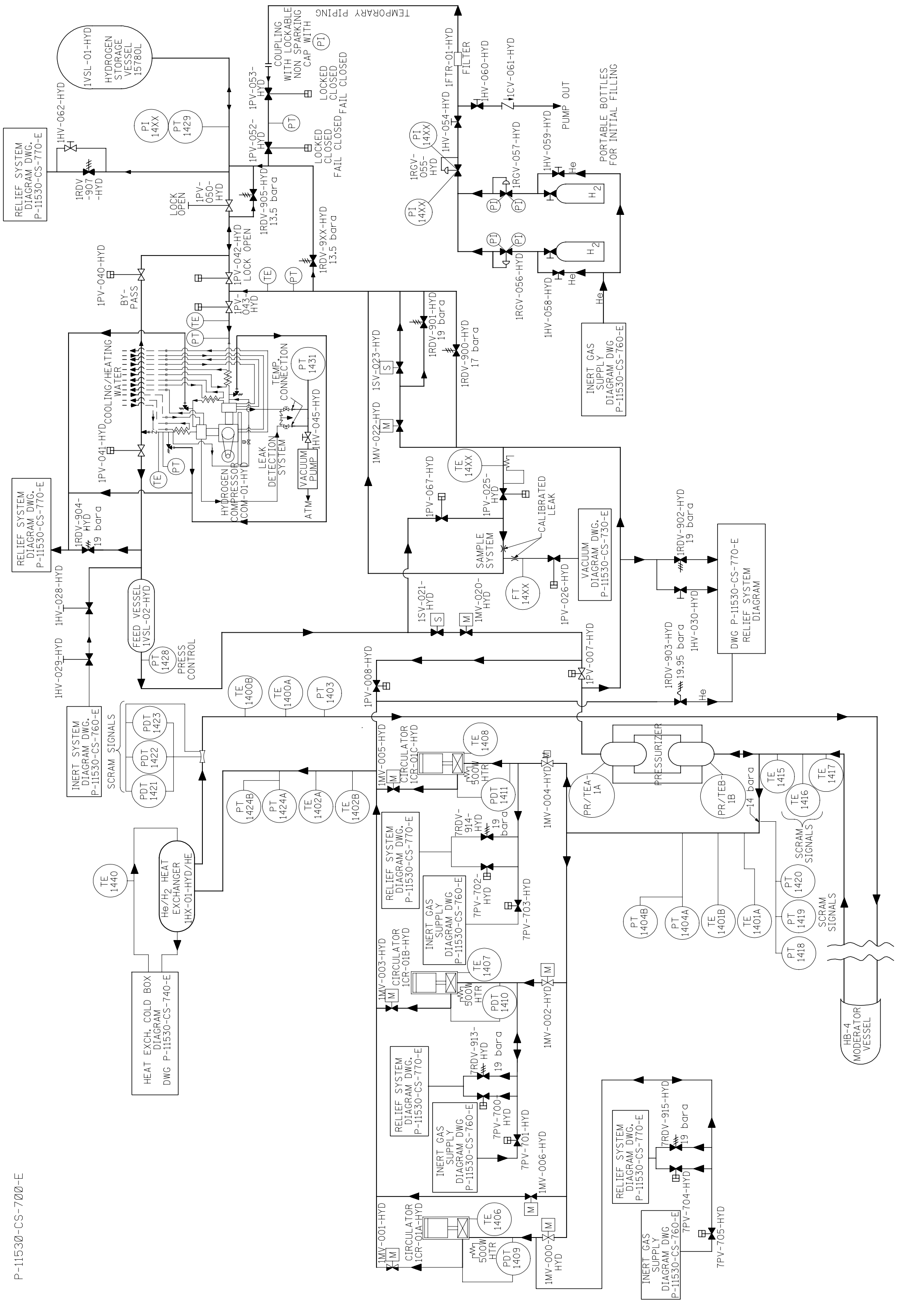

Figure 2.7. Hydrogen system flow diagram.

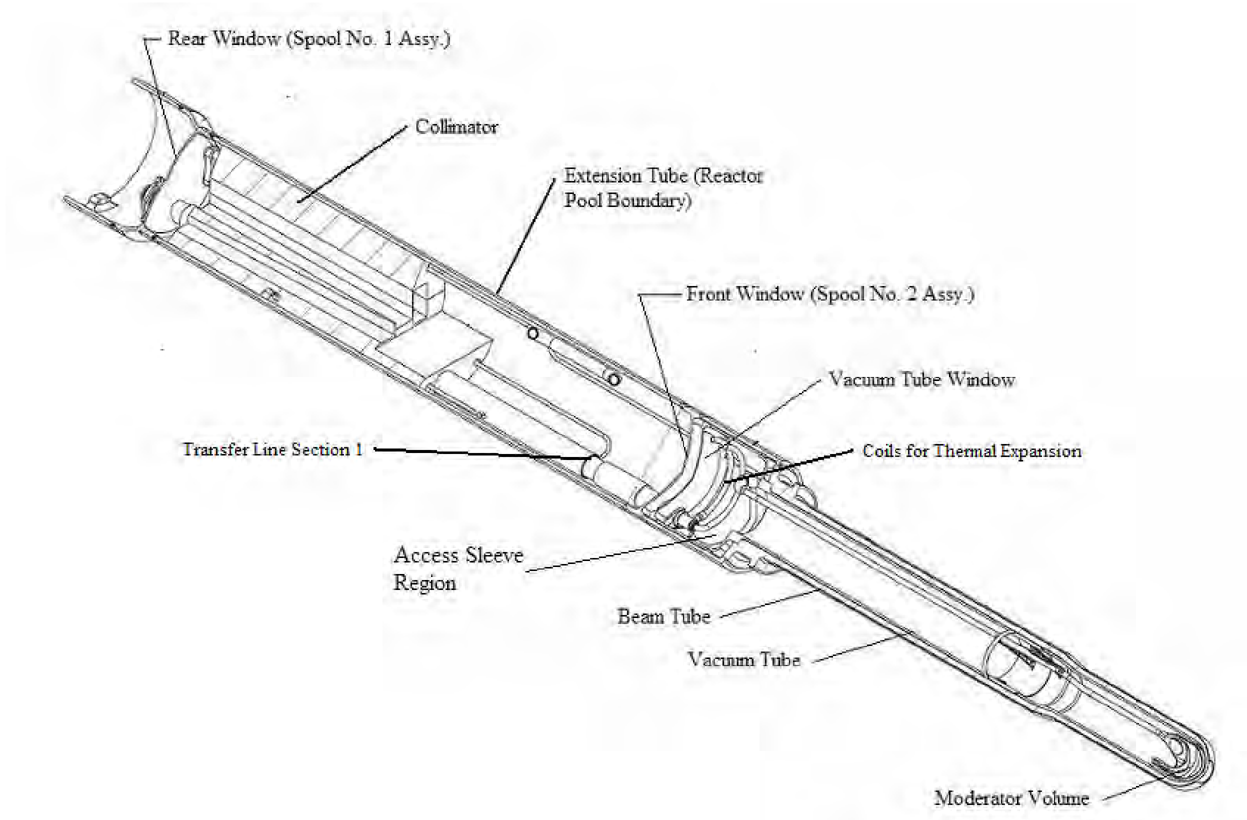

Figure 2.8. Beam tube internal structures.

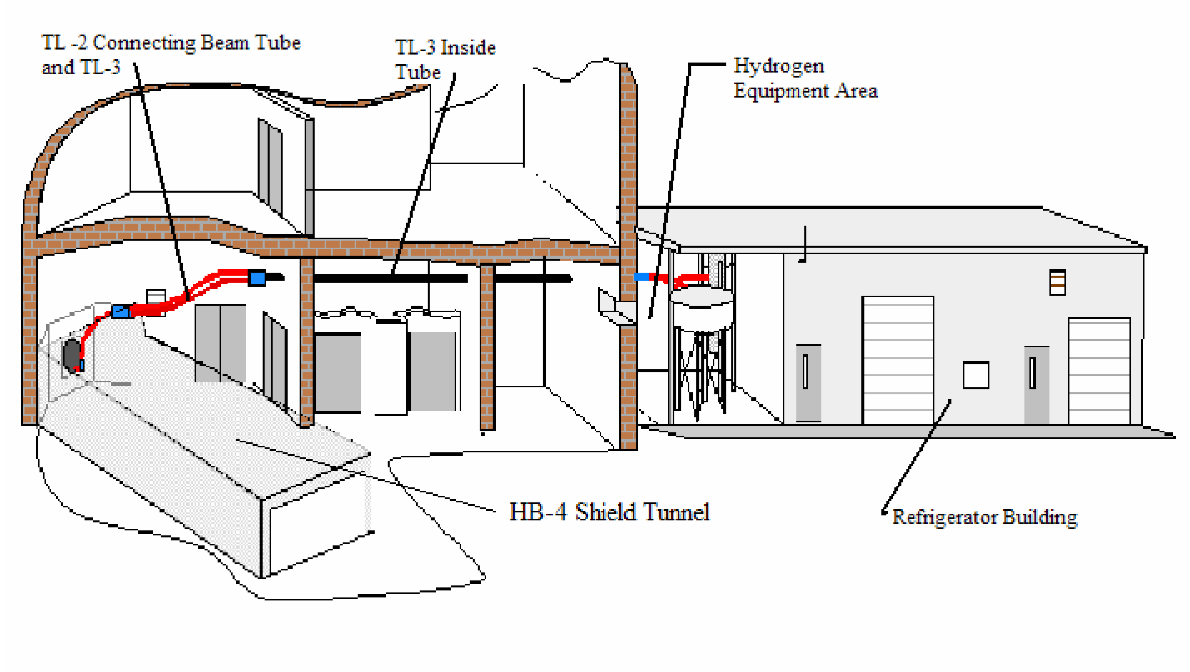

Figure 2.9. Transfer line route from HB-4 shield face to HEA.

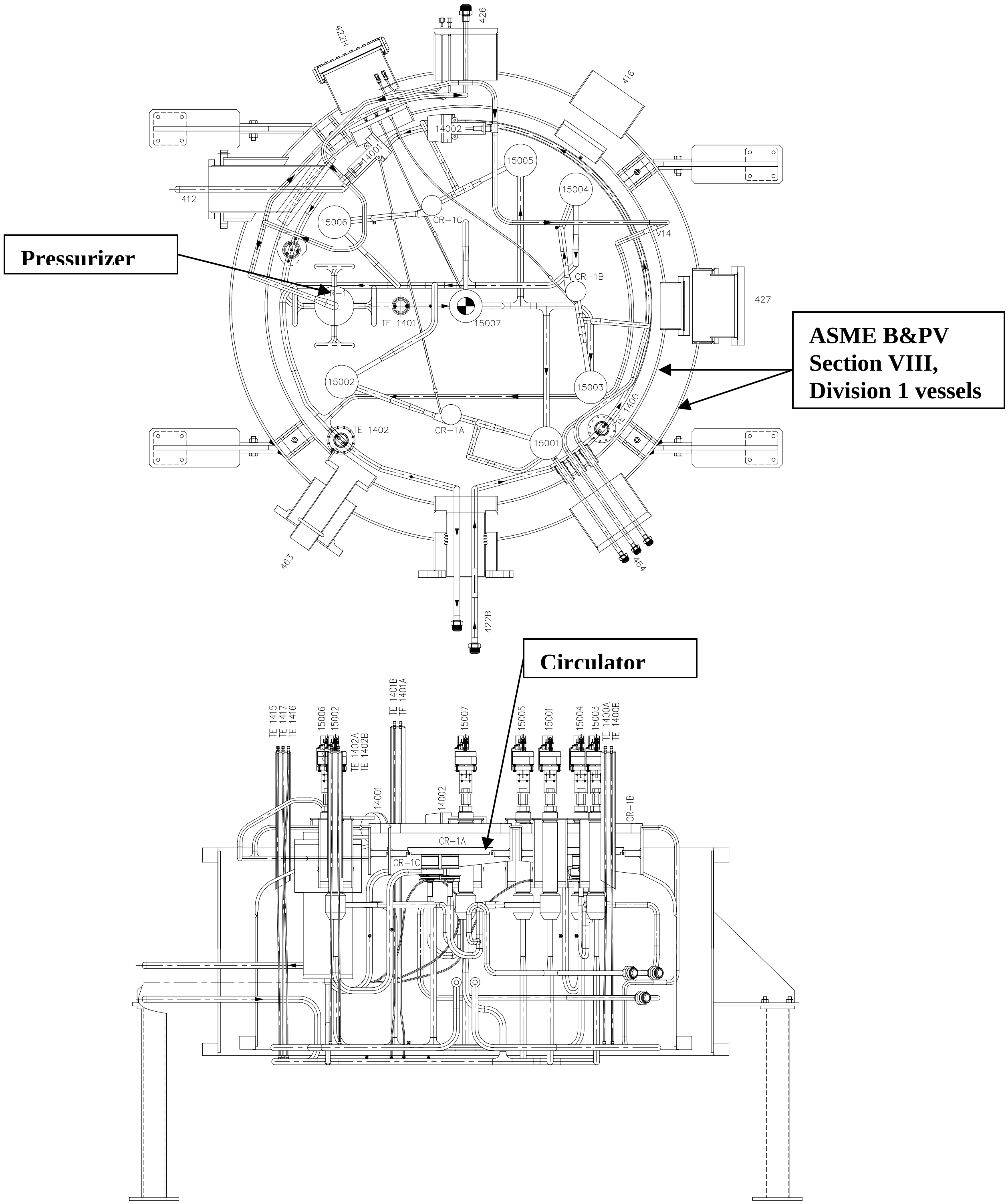

Figure 2.10. Pump module and internals.

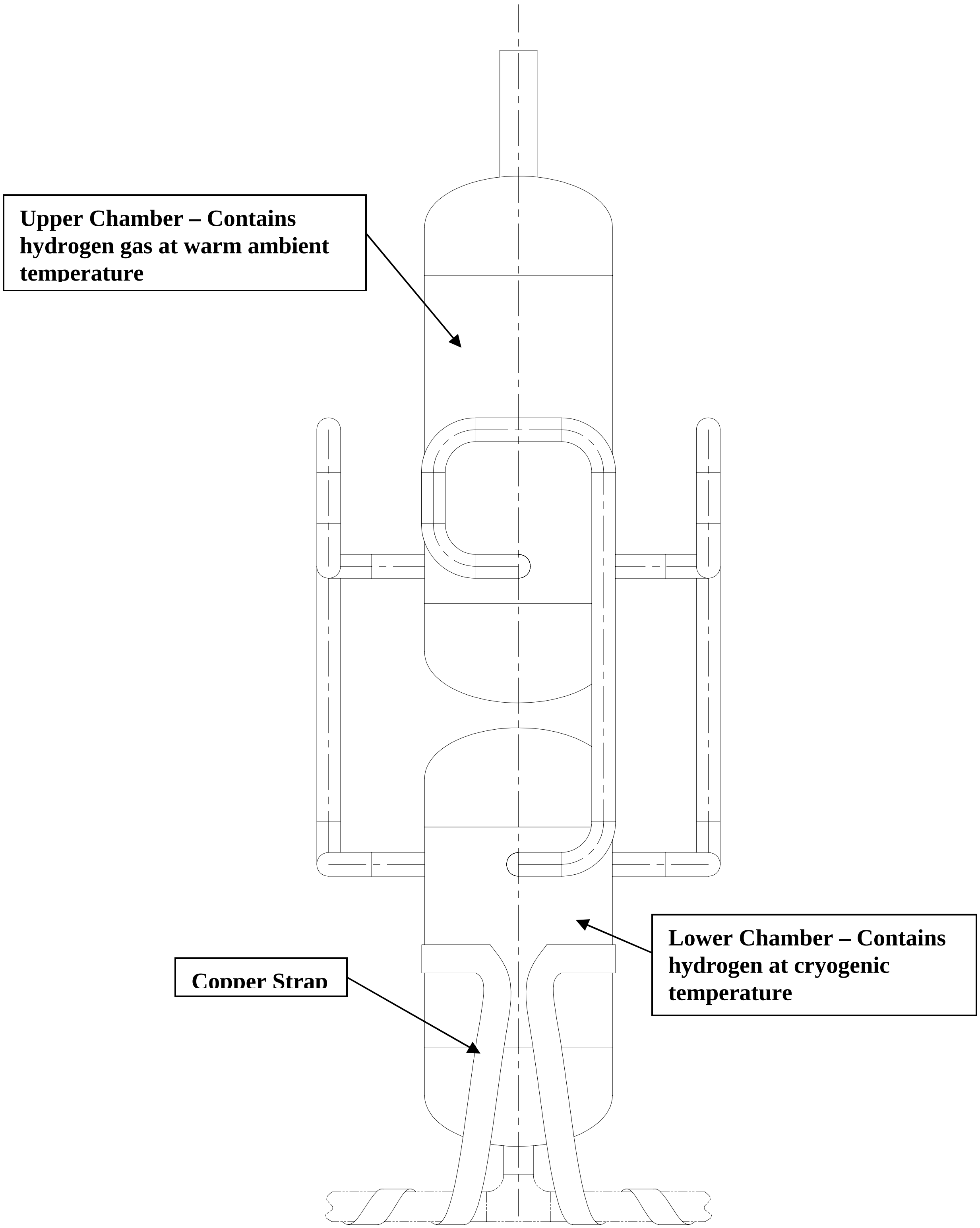

Figure 2.11. Pressurizer.

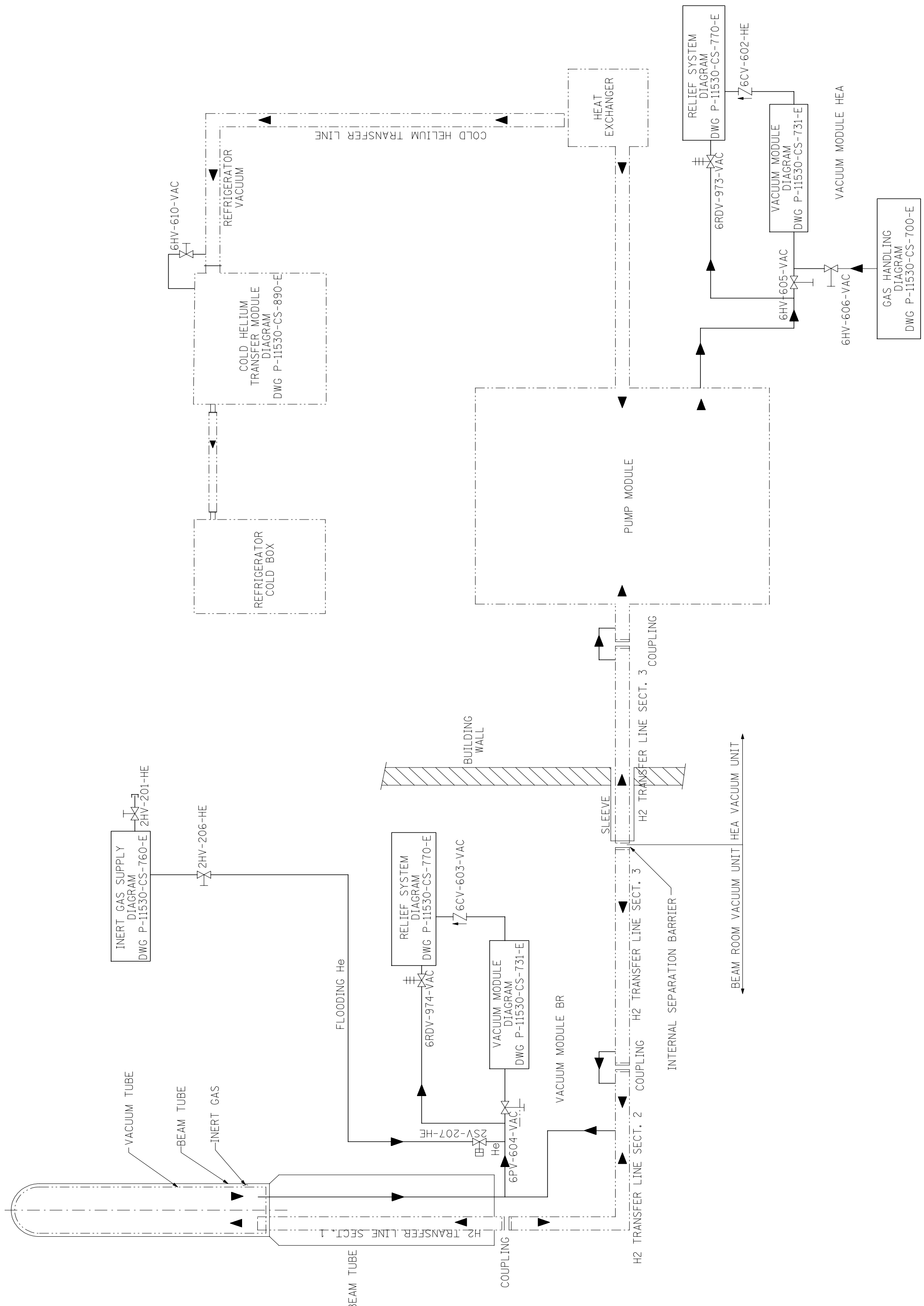

Figure 2.12. Vacuum systems.

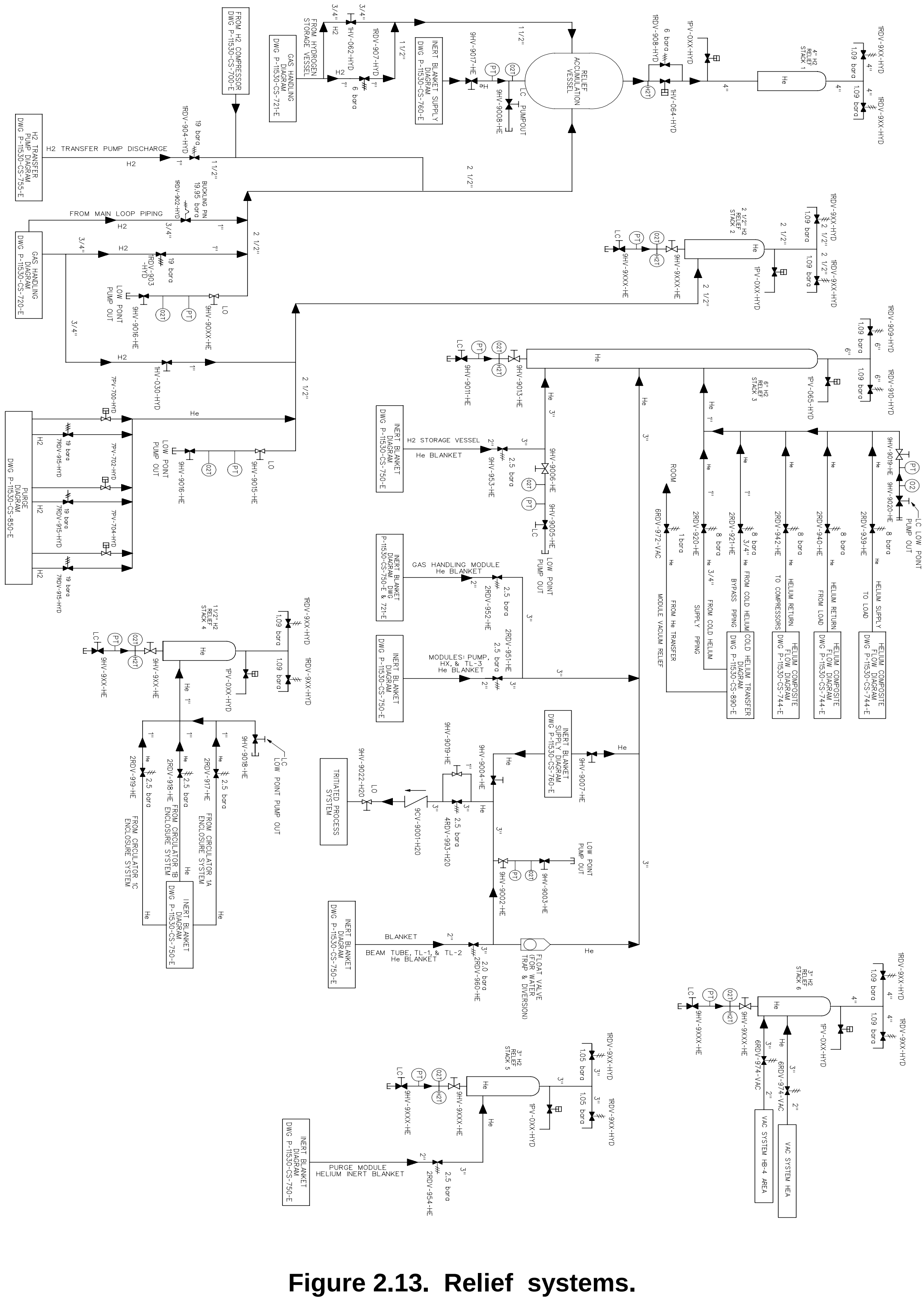

Figure 2.13. Relief systems.

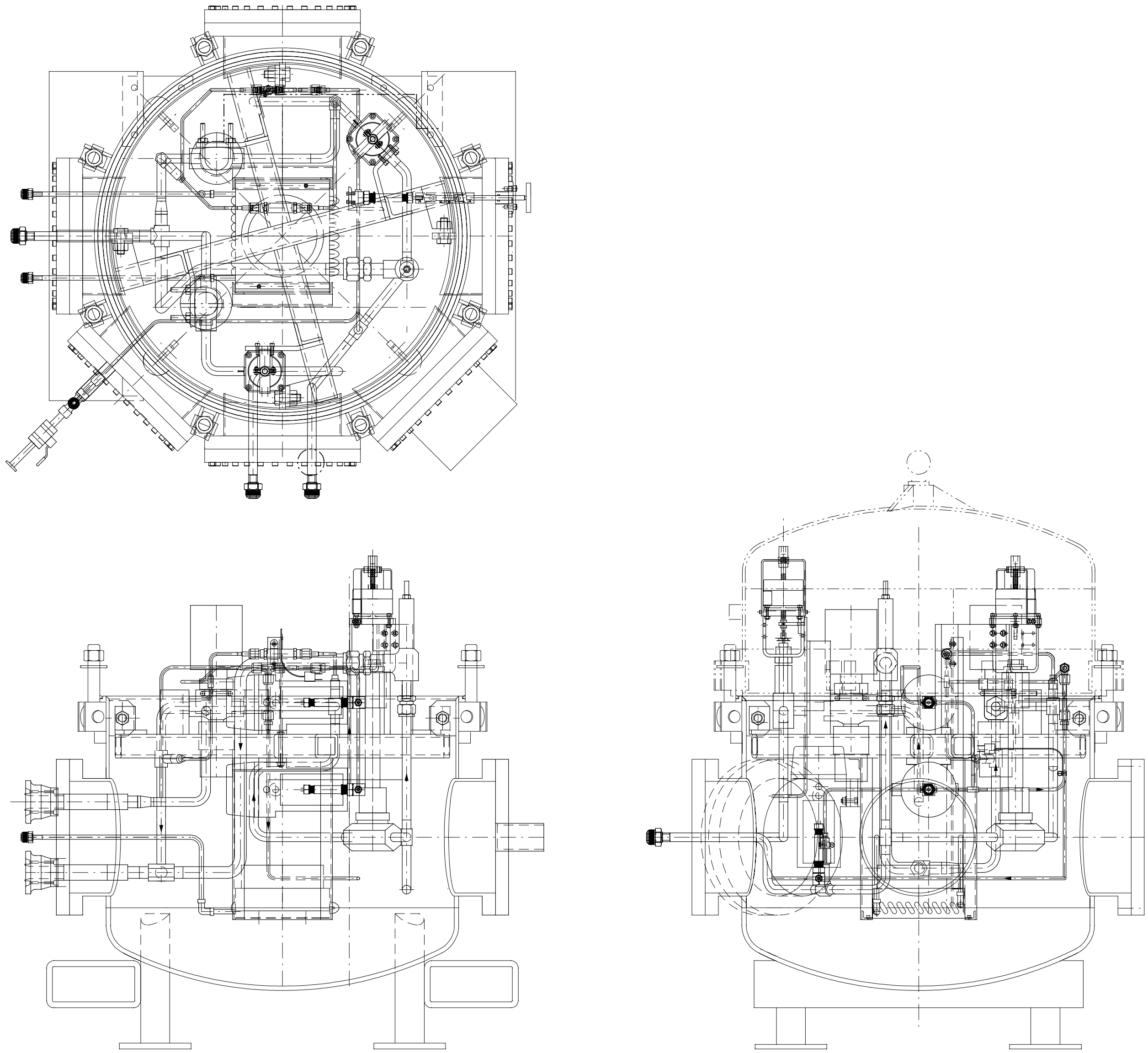

Figure 2.14. Gas Handling Module.

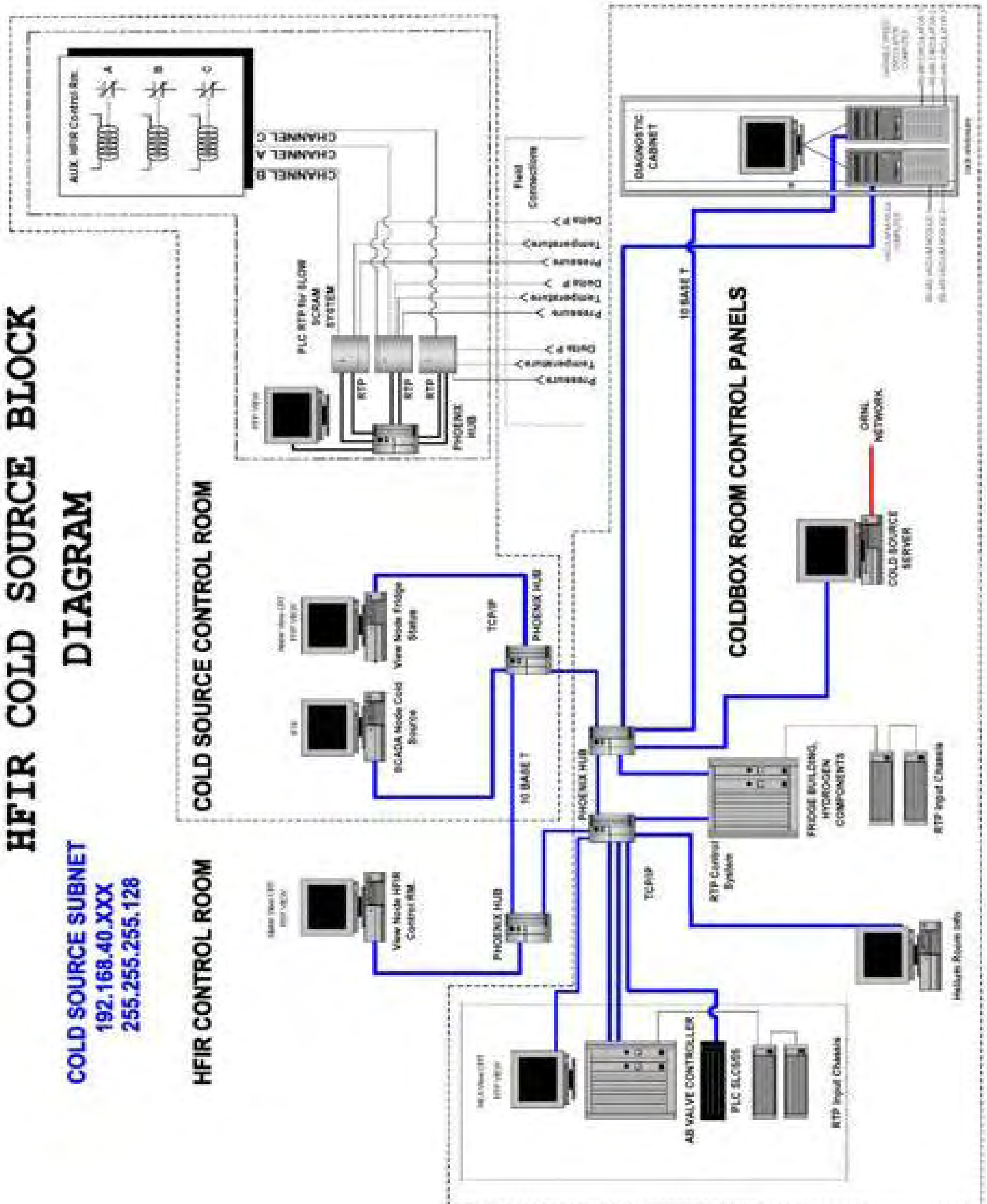

Figure 2.15. Instrumentation and control systems block diagram.