STATUS OF THE HIGH FLUX ISOTOPE REACTOR COLD SOURCE PROJECT

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BACKGROUND HISTORY

As stated at previous IGORR meetings, when the Advanced Neutron Source Project was cancelled in 1995 it was determined that there was an urgent need to upgrade the neutron scattering capability at ORNL by adding a cold neutron source to the HFIR facility. A feasibility study was performed in the summer of 1995 which concluded that a hydrogen cold source located in the HFIR HB-4 beam tube would produce a beam of cold neutrons with a brightness comparable to the best in the world. A Preconceptual Design Report was issued in December of 1995 following the feasibility study.

An official project was started in 1996. The objective of this project was “to design, qualify, fabricate, install, and test a hydrogen moderator facility for the HB-4 beam tube that will increase the available neutron flux delivered to instruments at wavelengths from 4 to 12 Δ (5 to 0.6 meV).” The principle functional requirement was that “The gain factor on brightness, as measured on HB-4, for these wavelengths should be comparable to existing cold sources of similar geometry (gain factor of at least 10 to 20 at 7 Δ).”

Early design work identified that a supercritical hydrogen system was the optimal approach for the retrofit of a cold source into our existing HB-4 beam tube. Physics analysis indicated that this approach would meet our design requirements and the supercritical condition gave several advantages under transient conditions.

A Concept Design Report was issued in May of 1998. This report contained detailed project goals and requirements, design descriptions of the major system modules and components, the design basis physics analysis, the design basis thermal analysis, and an initial safety analysis. The safety analysis included in this report addressed accident identification and their probabilities, initial scoping analysis of these transients, and the safety and quality level classifications for the cold source equipment.

In the time since the Concept Design Report was issued the focus has been on detailed design of the various modules and the procurement of the various components that make up the modules.

PRESENT PROJECT DESIGN AND PROCUREMENT STATUS

The detailed design of the cold source has been divided into eleven major modules:

1. Moderator assembly,
2. Gas handling system,
3. Pump module,
4. Heat exchanger system,
5. Cryogenic transfer lines,
6. Insulation vacuum system,
7. Refrigerator system,
8. Hydrogen vent system,
9. Cold source equipment building,
10. Purge system, and
11. Instrumentation and control system.

These modules are in various stages of completion. A short status and description of each system is provided in the following pages:

Moderator assembly - The moderator assembly consists of the moderator vessel, its support structure, and two short bellows (that are restrained to allow bending only) to allow axial flexibility of the inlet and outlet hydrogen pipes. The moderator vessel procurement specification has been written and detailed fabrication drawings have been prepared and approved. A contract to fabricate the vessel assembly is expected to be awarded to Micro Craft Inc. sometime in October of 1999. The 3-D model of the moderator vessel is shown in Fig. 1. The arrangement of the hydrogen inlet and outlet regions produces a cold neutron trap that increased our cold neutron beam brightness by about 30%. Testing of the prototype steel bellows is nearly complete. The bellows has been tested to 900,000 cycles at room temperature with no leak. We are starting further tests that will be performed under liquid nitrogen conditions that will be completed in a few weeks.

Gas handling system - The gas-handling module provides storage of the hydrogen inventory at ambient temperature and controls its movement and pressure as required during operation. A schematic of the gas-handling module is shown in Fig. 2. At the start of cool-down the gas-handling system raises the loop pressure to 14 bar by compressing the gas from the storage vessel. As cooling proceeds and its density increases, further gas is transferred in from the storage vessel to maintain the loop pressure. The vessel is sized such that under normal operating conditions, the storage vessel is reduced to a partial vacuum. The storage vessel is double-walled with a helium inert blanket between the two walls.

Pump system - The pump module provides a supercritical hydrogen flow of 1 L/s under normal operating conditions and a hydrogen gas flow of 2.25 L/s in a standby state where the gas is at approximately 80 K temperature. The module is also the nerve center of the control system where many of the loop parameters are monitored. The new aspect of the pump module system is that we are evaluating a change to a variable speed circulator. We have been working with Barber-Nichols, Inc. to develop a circulator for supercritical hydrogen that would have variable speed capabilities. This makes it much easier for the system to respond to changes in hydrogen density that occur in off-normal transients, cool-down and heat-up. A conceptual drawing of the pump module is shown in Fig. 3. We expect to place an order for circulators and the remainder of the pump module system sometime this fall.

Heat exchanger system - The heat exchanger is of the same aluminum core type used in the construction of our cryogenic refrigerator. This is a very compact type of heat exchanger with a very small fluid inventory of about 1.6 L. The only other component in this module is the double-walled heat exchanger containment vessel. A hard insulating vacuum is maintained between the heat exchanger and the inner wall of the containment vessel. Helium gas between the two walls of the containment vessel provides the inert blanket boundary. An order for the heat exchanger has already been placed with ALTEC.

Cryogenic transfer lines - The cryogenic transfer line module is composed of one long liquid nitrogen transfer line connecting the liquid nitrogen storage tank with the refrigerator system and three cryogenic hydrogen lines. The three supercritical hydrogen transfer lines connect the moderator vessel with the pump module. The first hydrogen transfer line is a fixed section of dual concentric transfer lines that attaches to the moderator vessel assembly at one end and passes through the beam collimator at the other end. The second hydrogen transfer line is also a fixed line that connects to the first hydrogen transfer line at one end, snakes under the beam shutter and passes through the biological shield. The third transfer line is a long flexible transfer line that passes out of the reactor building into the hydrogen safe room building. The first hydrogen transfer line section has been ordered and specifications have been written for the liquid nitrogen transfer line and the two remaining hydrogen transfer lines.

Insulation vacuum system - The vacuum surrounding the hydrogen system is divided into two sections: the vacuum inside the beam tube and the vacuum surrounding the rest of the system. Each vacuum section is controlled by a roughing pump and a high level turbo vacuum pump and each vacuum section is monitored by independent gas analyzers. The original concept called for the operation of the vacuum pumps in a helium inert atmosphere. However, testing has indicated an arcing problem in helium and nitrogen is now being used as the inert gas. A subcontract to supply the vacuum system equipment is expected to be placed early this fall.

Refrigerator system - Refrigerator requirements were established early in the cold source project. An approximate 50% margin was added to the 2.3 Kw requirement to establish a 3.5 Kw refrigerator heat removal requirement with a return helium temperature of 20 K. The refrigerator was ordered in 1996 and delivered in January of 1999 at a total cost less than $2M. The refrigerator equipment has been installed in the new cold source equipment building and piping connecting the various components is being installed. Testing of the refrigerator system is expected to begin late this fall. Since liquid nitrogen is relatively inexpensive in East Tennessee, a liquid nitrogen precooler was determined to be very cost effective. The refrigerator was also configured so that the liquid nitrogen can be used as a backup passive cooling system, providing a cold source standby state with a hydrogen temperature of around 80 K.

Hydrogen vent system - There are two major vent lines: the first system transports gas from the vacuum pumps and from any of the hydrogen pressure safety relief systems to a safe height for release to the atmosphere. Nitrogen gas is continuously passed through this system maintaining a positive pressure of about half a bar to reduce the potential for back flow of air into this vent line. The second vent system provides constant evacuation of the safe room. If hydrogen is detected in the safe room, the exhaust is raised to the equivalence of one room air change per minute. Both vents are exhausted at a point above the roof of the reactor building.

Cold source equipment building - With no space inside the reactor building to locate the cold source system equipment, a new building had to be constructed to house the majority of the hydrogen bearing equipment and the refrigerator system. This building is 40 feet by 90 feet with a 14 foot ceiling and was completed this summer.

Purge system - The hydrogen system must be purged prior to loading hydrogen and prior to breaking into the closed hydrogen loop for maintenance. The purge system module provides the components necessary to perform purge functions.

Instrumentation and control system - The cold source control system has four major functions: 1) to monitor and control the hydrogen temperature and pressure; 2) to monitor vacuum systems and other gases used for monitoring or inert blanketing; 3) to provide interlocks between components of the cold source to ensure its safe operation at all times; and 4) to interface with the reactor control system to initiate a reactor shutdown in the event of a major cold source malfunction. The main control system is PC-based, using windows-interfaced software. The preliminary control system was tested as part of a semi-prototypic hydrogen loop test performed in 1997 resulting in several modifications to the control concept. A schematic of the control system has been prepared and is presently being reviewed. A list of parameters to be annunciated has also been developed and is being reviewed.

SAFETY

A probabilistic approach has been used to identify off-normal events that should be analyzed. This effort identified six insufficient cooling scenarios, four over pressure scenarios, and a couple of tank rupture events to be evaluated. A detailed system model was developed using the ATHENA code to evaluate the system response to these transients. Detailed analysis of these transients has resulted in some design modifications necessary to allow the system to better respond to these off-normal conditions.

The system responses to these events are being re-evaluated in light of the desired design change to variable speed circulators. Although the variable speed circulator is expected to provide better response to off-normal conditions, it is important to verify this assumption.

Although hydrogen detonation events were determined to be beyond design basis, several theoretical detonations were examined as bounding hazards. Three types of detonations were examined inside the beam tube and the beam tube was found to survive all three. A maximum credible detonation in the safe room was also examined and the results were deemed acceptable with no impact on the safety of the reactor.

A preliminary safety assessment report is expected to be issued during the spring of 2000. This safety assessment report will be used to obtain approval to perform out-of-pile testing of the system with hydrogen. Final approval to insert the new HB-4 beam tube containing the cold source into the reactor would be obtained following the out-of-pile testing.

SCHEDULE

The present schedule is based on completion of the majority of the design effort by the end of this calendar year. Safety reviews would begin in the spring of 2000. Testing of the complete system out-of-pile would be performed during the summer and fall of 2000. If all goes well, the cold source should be loaded into the reactor and be operational approximately one and a half years from now. This schedule, however, is dependent on sufficient budget support, no new unresolved safety issues, and completion of reviews and approvals in a reasonable period of time.