Cold Moderator Test Facilities Working Group

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1. FINDINGS

Testing is a vital part of any cold source development project. This applies to specific physics concept verification, benchmarking in conjunction with computer modeling and engineering testing to confirm the functional viability of a proposed system. Irradiation testing of materials will always be needed to continuously extend a comprehensive and reliable information database. An ever increasing worldwide effort to enhance the performance of reactor and accelerator based neutron sources, coupled with the complexity and rising cost of building new generation facilities, gives a new dimension to cold source development and testing programs. A stronger focus is now being placed on the fine-tuning of cold source design to maximize its effectiveness in fully exploiting the facility. In this context, pulsed spallation neutron sources pose an extra challenge due to requirements regarding pulse width and shape which result from a large variety of different instrument concepts.

The working group reviewed these requirements in terms of their consequences on the needs for testing equipment and compiled a list of existing and proposed facilities suitable to carry out the necessary development work.

2. NEEDS AND REQUIREMENTS

2.1 Basic Data Needs

- Determination of scattering laws for candidate moderator materials such as solid methane, ethernet deuterated methane, mesithylene and others in the temperature range 20 - 60K as a basis for selecting potentially good moderator materials and to enable computer modeling of the expected performance.
- Comparative studies of respective cold moderator neutronic performances.
- A study of radiation effects on solid methane, mesithylene and other materials within a temperature range of 15 - 20K and a dose rate of 0.1 - 10 MGy/h for samples 1 - 5mm thick in different radiation environments (over a range of no/ ratios) to assess life expectancy and possible measures for its extension. This includes:
  - Concentration of radicals (giving rise to stored energy release) versus neutron dose, dose rate and temperature.
  - Degradation and rate of hydrogen release under irradiation using residual gas analysis.
  - Conditions for spontaneous release of stored energy.
  - Pressure loading on the moderator container during irradiation and during annealing (release of radiolytically generated hydrogen).
  - Effect of the amount of loading and heating rate on this pressure.
  - Thermal conductivity of solid moderator materials before and after irradiation.
  - Effects of hydrogen build up on volumetric changes (swelling) and intergrity of samples (i.e. risk of damage to solid moderator by internal pressure due to radiolytic hydrogen).
  - The nature of some hydrocarbons generated in the process of moderator degradation in radiation fields.

2.2 Engineering and Systems Testing

While heat removal systems and refrigeration loops are relatively well understood, special requirements of new types of cold sources and retrofits to existing neutron facilities tend to be subject to rather stringent boundary conditions. This makes it desirable, and in some cases even mandatory, to carry out tests on the full system or on parts thereof, before putting it in operation in a radiation environment. Such tests in cold condition can constitute a very large effort, especially if modifications to vacuum insulated components and subsystems must be made. Access to a large vacuum chamber with sufficient cryogenic capacity would be of great help in this context. Ideally, if a new cold moderator concept is developed in the frame of a new large project, "in pile" testing in a realistic environment, albeit possibly at reduced heat loading, would be desirable.

2.3 Requirements for Test Facilities

To examine potential moderator materials in terms of their frequency spectrum, optical spectroscopy can be used in many cases, but incoherent inelastic neutron spectroscopy is to be preferred, because this ensures that all modes which neutrons can couple to are actually accounted for. Suitable spectrometers should:

- cover a large energy range (<1meV to several 100 meV)
- have good energy resolution especially for low energies
- allow absolute calibration for cross section determination.

A neutron generator (spallation target or photonuclear facility) with the following characteristics is desirable:

- Fast neutron pulse lengths of less than 0.5μs
- Neutron intensities of some 10^{10} to 10^{12} n/pulse
- Repetition rates of 10 Hz or less
- Easy access to the moderator
- Flexible cryogenic equipment (variable temperature and cooling power)
- Possibility to vary the moderator environment (pre-moderator, reflector, shielding)
- Opportunity to change from direct time-of-flight to high resolution crystal analyzer time-of - flight measurements
- Detectors of known sensitivity for a wide range of neutron energies

General requirements for irradiation facility are as follows:

- Radiation flux of approximately 10^{11} - 10^{12} n/cm^2/s
- Capability of variable neutron to gamma ratio
- Sufficient flexibility to accept cold samples up to 10 cm x 10 cm
- Temperature range of 15 K - 60 K
- Accessibility for easy handling of samples and cryostats.

3. SPECIFIC FACILITIES FOR MEASURING SCATTERING LAWS

High performance neutron spectrometers using time of flight for density of state measurements are available at many neutron sources. Spectrometers on pulsed sources particularly well suited for the present context include:

- QENS, LRMECS and HRMECS at IPNS, Argonne National Laboratory, US
- TFXA, MARI, IRIS and HET at ISIS, Rutherford Appleton Laboratory, UK
- FDS at the Lujan Center, Los Alamos National Laboratory, US
- INC at KENS, Tsukuba, Japan
- DIN-2 at IBR-2, Joint Institute of Nuclear Research, Dubna, Russia

4. SPECIFIC FACILITIES FOR MEASURING MODERATOR PERFORMANCE

4.1 Moderator Test Facility at the Hokkaido Electron Linac

An established test facility exists at the electron linear accelerator at Hokkaido University, Japan. This setup allows different configurations of target-moderator-reflector arrangements to be tested in a very flexible way. Pulse shape evaluation as well as spectral measurements are possible and many studies have been carried out to provide a database for cold moderator systems design and to check computed design data.

Linac Data

- Maximum beam energy 45 MeV (15 and 30MeV are also possible)
  Pulse width 10 ns to ~3 μs on demand
- Beam current ~140, μA maximum average
- Rep rate 1~200 pps and single shot
- Beam size 10 mm diameter (larger is possible)

A fixed or portable cold moderator can be accommodated and pulse shape can be measured by a mica crystal spectrometer or 20 K PG crystal spectrometer. The facility is available for collaborative R&D work.

4.2 COSY Neutron Source Test Facility (proposed)

COSY is a 2 GeV proton synchrotron at the Forschungszentrum Juelich (FZJ, Germany), which has one beam line dedicated to neutronic experiments. Currently, only slow (multiturn) extraction is possible, and the beam line is mostly used for experiments relating to the physics of spallation neutron generation. However, a study is under ways to fit the ring with single turn extraction capability. This would allow installation of a moderator test facility similar to the one in Hokkaido, but with realistic spallation target geometries, since proton energies from a few hundred MeV up to 2 GeV would be available. About 10^{10} protons per pulse would be available at a repetition rate around 0.2 Hz (depending on energy).

4.3 KEK-Booster Facility (proposed)

The 500 MeV booster proton synchrotron located at KKK was presented as a possible test facility for target-moderator-reflector assemblies. The test area would be a proton dump between the accelerator and the experimental facility (KENS). The proton beam characteristics are as follows:

- Beam energy 500 MeV
- Protons/pulse 2×10^{12}
- Reprate from an arbitrary low frequency to 20Hz

While the energy is lower than might be desired, a very low beam current is possible, reducing radiation problems for mock up testing. The proton dump is in a small concrete shielded room with a concrete shielded door. Time-of-flight measurement could be made by providing a neutron flight path through the door. It would take time to prepare this area for testing and a safety assessment would be required.

4.4 ASTE (AGS Spallation Target Experiments) - Collaboration

A collaboration has been formed between several US, European and Japanese Laboratories to prepare and carry out a test program at the Brookhaven "Alternating Gradient Synchrotron" facility.

Current AGS performance data are:

- Pulsed proton beam energy of 1 .5 GeV to 24 GeV
- 8 bunches/pulse, a minimum of 30 ms apart
- Rep rate 1.6 sec
- Maximum number of p+ per bunch about 7.5×10^{12}
- Bunch duration about 40ns

Without full aperture kicker the p+ intensity is a function of energy below 18 GeV. Currently the beam diameter at the target position is 20 cm at 1.5 GeV, but beam optics will be available as of 1998, to control the beam footprint on the target. A 20cm diameter liquid Hg target (stainless steel contained) is sited close to the beam stop in the "U"-line within about 7 m of earth shielding.

First test measurements were performed in 1997, with a bare target. Quantities measured include:

- beam profile data using foil and wire chamber devices,
- spatial and spectral neutron leakage using foil activation,
- pulsed strain on the mercury containment using laser interferometry, and
- temperature distribution in the mercury at 24GeV

Measurements planned for 1998 will extend the data over several energies with improved monitoring. A reflected system will be installed that can offer the option to vary relative positions of the target and moderator. This will provide an opportunity to carry out ToF- measurements from both the bare target and the moderator through flight paths in the tunnel shielding. Provision will be made for the installation of a closed cycle cold moderator and the beam optics will allow the proton beam footprint on the target to be varied in order to verify the results of theoretical calculations.

Although cryogenic moderator testing is part of the program, ASTE aims primarily at full power tests for engineered high power spallation assemblies. It is not intended for routine testing of new ideas or to provide basic information in a systematic way. This would require a more readily accessible facility, which might well be of much lower power.

5. SPECIFIC FACILITIES FOR IRRADIATION TESTS

5.1 Joint Institute for Nuclear Research (JINR)

The Frank Laboratory of the JINR (Dubna, Russia) is operating several facilities which meet the requirements listed above.

Channel #3 at the IBR-2 Reactor is equipped for irradiation of large samples (up to 20 by 40 cm) with a fast neutron flux of $10^{10} - 8 \times 10^{12}$ n/cm^2/s (up to 3 MGy/h) and gamma radiation up to 1 MGy/h. In the past, an installation for irradiation tests on solid methane at 20 - 30 K was in operation with which some problems have been investigated. Currently, the rig is in storage. Further use is difficult due to the high level of radiation and it would take about one year and some investment (approximately 50K$) to reconstruct the installation.

Some of the requirements could be met by the FLNP Van de Graaf accelerator providing 3 MeV p+. Preferably, studies on the stability of small samples and chemistry research could be performed with the proton beam. An installation for such an application has been designed, but has not yet been constructed.

5.2 Penn State TRIGA Reactor

IPNS (Argonne National Laboratory) has proposed testing solid methane under irradiation at the Penn State TRIGA reactor. The facility as projected (Figure 1) could meet the requirements mentioned above. The safety case for the installation has been prepared and approval has been obtained, but currently the activities are on hold because the booster target development program at IPNS has been suspended.

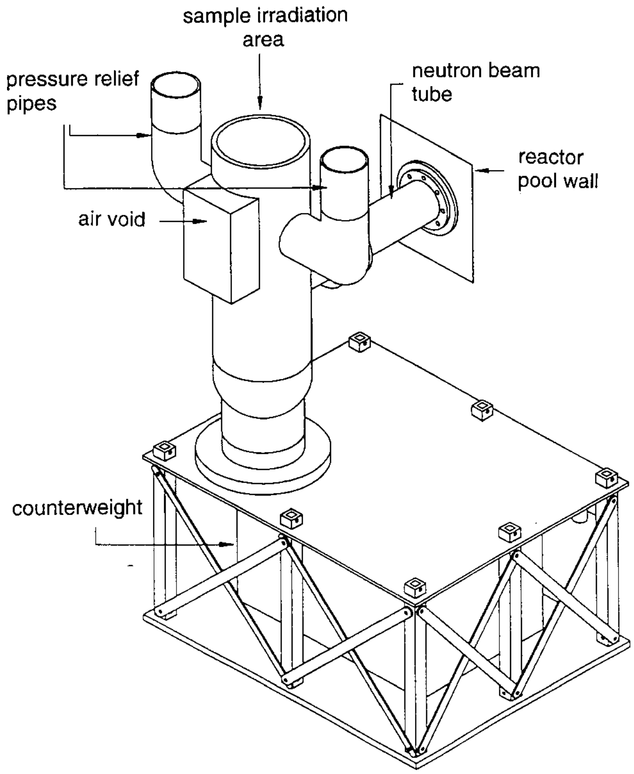

Figure 1. Moderator Test Insert Designed by ANL for the Penn State TRIGA Reactor (1 MW).

A suggested experiment would help evaluate the build up of solid hydrogen-poor residues, including graphite, in a methane moderator. This would be done by nondestructive imaging of the buildup distribution using a neutron pinhole camera. A neutron absorber such as B_4C would used for the pin hole and the relative brightness over the moderator surface would be mapped downstream by a position sensitive detector or by standard radiography equipment.

5.3 CARE Research Reactor

The main emphasis of the ISIS moderator development program currently is to find a chemical additive that inhibits the formation of hydrocarbons in the liquid methane moderator. The chemical engineers postulate that the addition of a selected hydrocarbon, such as propane or ethane, will inhibit methane breakdown and the production of gaseous hydrogen and long chain hydrocarbons.

The team is preparing tests on the CARE reactor of Imperial College, London University. This is to examine the breakdown mechanism of liquid methane under radiation. (Figure 2).

Small samples (40 cc) of liquid methane plus additives will be cooled using a helium gas circuit, close to the reactor core. The quantity of hydrogen and hydrocarbons produced will be measured after the methane has been frozen out of the irradiated sample.

Preliminary radiation dose maps of the in-core end of the beam tube have been made with a maximum dose of 0.034MGy/hr.

RAL personnel are now awaiting approval of the safety case by the CARE reactor safety committee. It is hoped to run a series of tests in early 1998.

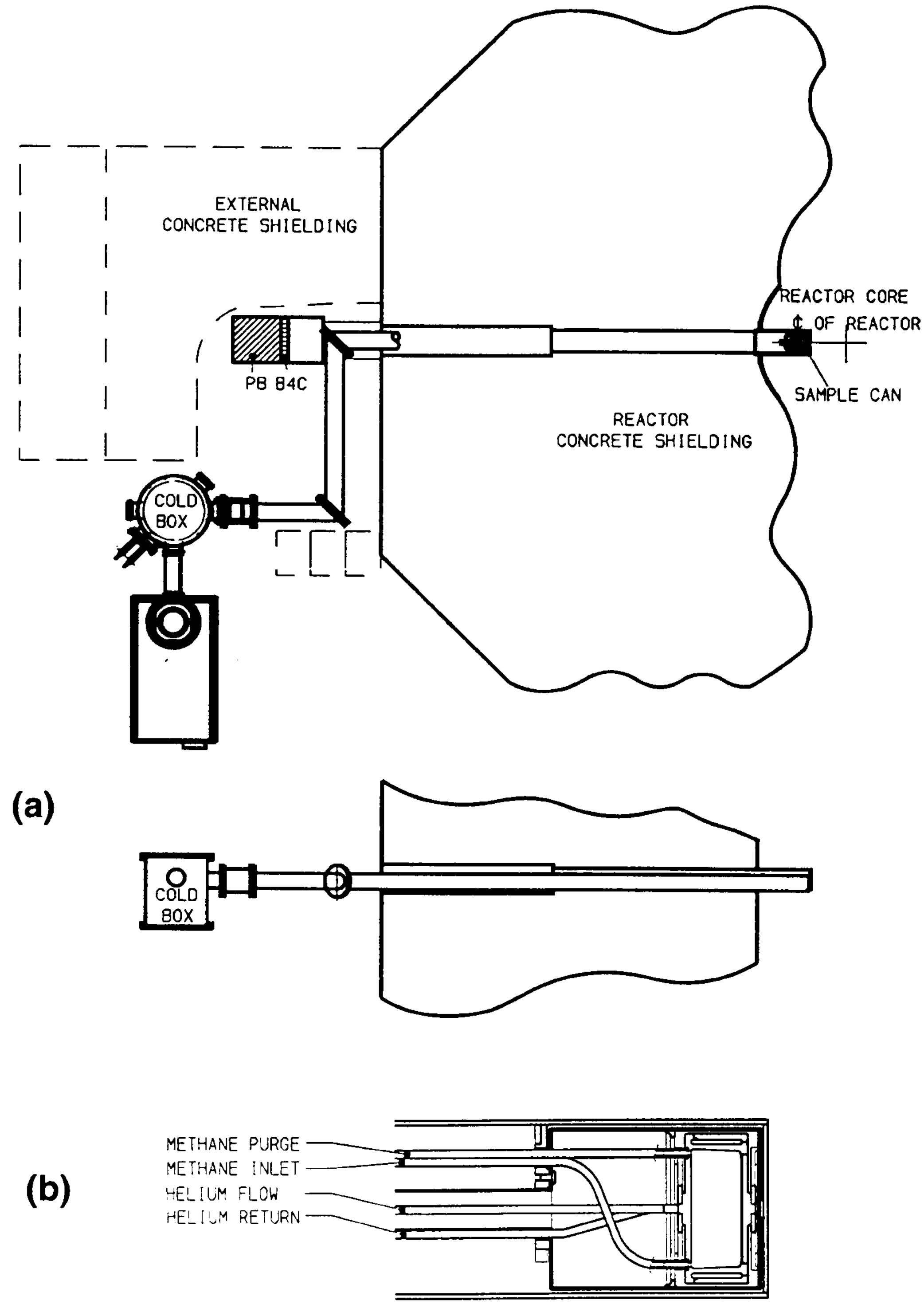

Figure 2. The CARE Reactor Test Experiment. (a) Schematic Layout of the Experiment (b) Cross Section of the Sample Can

5.4 ISIS

ISIS has agreed to contribute some beam time to well specified measurement proposals to characterize moderator performance. Preliminary proposals at the workshop so far include:

- Using a pinhole collimator to image the moderator on a detector (see above).
- Measure the energy spectrum from the ISIS hydrogen moderator with varying power deposition.
- Measure spectrum as a function of temperature from the hydrogen moderator.
- Test run the hydrogen moderator with hydrogen in supercritical condition.

Firm proposals will be required before beam time can be offered in these areas.

6. FACILITIES FOR ENGINEERING AND SYSTEM TESTING

Probably, the field of cold moderator development has not sufficient activity to warrant construction and operation of dedicated full system test facilities. However, the working group has identified two opportunities which have been or can be used to test full systems:

6.1 Cryogenic System Testing

Functional testing of the HFIR cold source system under development at ORNL was carried out at the Arnold Engineering facility in Tullahoma, Tennessee. A large vacuum chamber, used for the testing of satellites, allowed building and operating a simple mockup of the entire loop. Correct pipe diameters, lengths and elevations were used, and reconfiguration was very easy as the whole loop was completely exposed. The chamber measures 10 m in diameter and 22 m high inside. A helium refrigerator line is piped into the chamber with a cooling capability of about 3 kW at 20 K.

It was planned to simulate cool-down behavior, steady state operation, simulated reactor on/off procedures, and transition to a standby state, which allows the cold moderator to be made safe with the reactor at full power in the event of a system failure. The only test not completed was the last, which was terminated by a trip of the chamber vacuum resulting from a cooling water pipe leak in the test equipment.

A team of competent engineers and technicians supports chamber operation and the complete pump-down time is about 8 hours to 10^{-6} torr.

A safety case is required for each test but, this would be relatively easy having already carried out tests of this type.

6.2 Testing in a Realistic Radiation Field

SINQ at PSI (Switzerland), in its target facility has two systems of interconnected (T-like) penetrations in its D_2O moderator (Figure 3). The one with the wider access tube is occupied by the current cold moderator (see paper in these proceedings). The second one has a vertically displaced through tube, passing close to the target, which is interconnected at right angles by a service duct 10 cm wide and 30 cm high. The horizontal through tube changes its vertical height at the interconnection. This arrangement is flexible enough to accommodate many different moderator configurations and has been conceived with the postulated solid methane pellet moderator in mind, as discussed in a paper presented at ICANS XIII. The moderator can be viewed from both sides, or conversely, two side by side moderators could be considered. An ambient temperature water scatterer currently occupies the space, but this location could be made available to be an excellent future test facility. Of course, SINQ is not a pulsed source and therefore only time average properties can be examined.

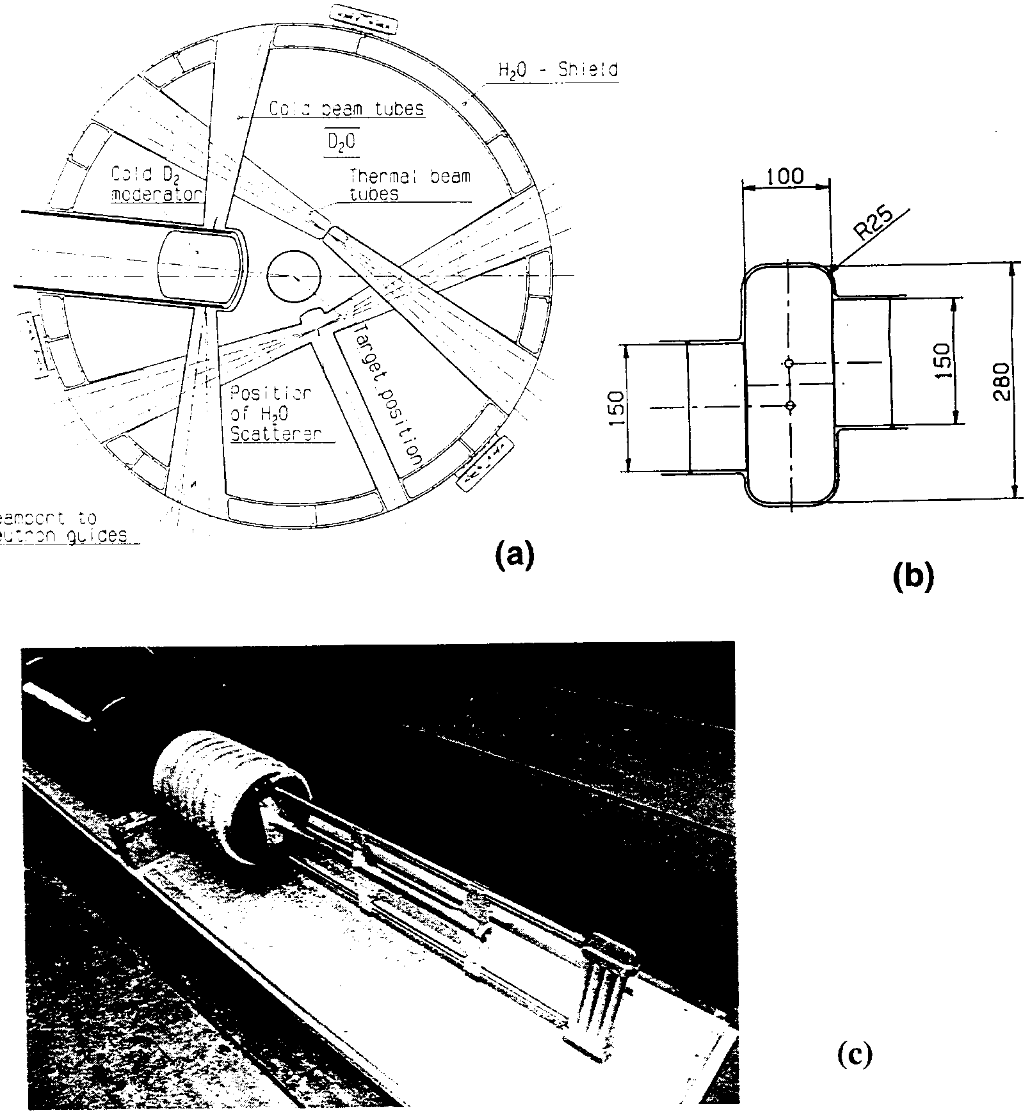

Figure 3. The SINQ D20 Moderator Tank with its T-Shaped Penetrations for Scatterer/Moderator inserts. (a) Horizontal section through the moderator tank (b) dimensions of the tubes holding the current H20 – scatterer (c) View of the current insert with H2O scatterer.

7. ANCILLARY AND AUXILIARY EQUIPMENT

While most of the emphasis in current cryogenic moderator development work is on suitable high hydrogen density materials and full systems design, some efforts to improve components or develop new ones have been reported.

A new circulator for supercritical hydrogen was presented by the RISϕ Laboratory. This features an enclosed rotor assembly allowing all heat generated in the motor windings to be removed externally to the cryogenic system. The design flow rate is about 0.28 l/s against a developed head of 0.5 bar. Both shaft bearings are self-lubricating ceramic making for very high potential reliability.

A procedure to manufacture solid methane pellets is being studied at ORNL in an effort to examine the viability of a pelletised methane moderator system where radiation damage products would be contained in the solid pellets which would be removed from the moderator vessel without melting.

A cryogenic pellet transport system for the same general purpose is under development by a task group within the ESS R&D collaboration, together with alternative pellet producing systems and porous media spheres that could be used as carriers for the moderator substance proper.

8. CONCLUSIONS

The Workshop in general clearly showed that, despite a large body of experience with cold moderators world wide, there are still many ideas around and efforts going on that carry a potential for significant improvements in cold moderator performance. While predictive capabilities of computer codes have improved dramatically in both neutronic performance and fluid dynamics behavior, the need for experimental testing still persists and even grows as more advanced concepts are being put on trial. Opportunities and facilities for such tests exist or can be created at various locations around the world. The scale of effort, however, which is frequently associated with this kind of work makes international collaboration and co-operation highly desirable. Some more formal forum for such collaborations, which could conceivably well be established under an OECD umbrella, would certainly be an important asset to catalyze and facilitate inter-laboratory agreements.