Chamber and Chamber Driver Interface working group

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The requirements for the chamber and chamber driver interface

For a summary of IFE Chamber Designs and Requirements see Wayne Meier's presentation: http://ahif.lbl.gov/presentations/110523MeierHIF-Workshop.ppt?attredirects=0&d=1

The chamber and chamber driver interface have to be designed to meet the following requirements:

1. The neutrons need to be moderated to prevent damage to the chamber and radiation to the external environment.
2. The beams have to be focused on targets with required precision,
3. Each target must be accurately injected into the chamber.
4. The accelerator and final focus system should be shielded from debris, radiation and neutrons.
5. The interface between chamber and accelerator requires pumping systems to pump down from chamber pressure (about 1mTorr) to accelerator pressure (for 1 km of $\sigma_s \sim 10^{-15}$ cm^2 electron stripping of 5-10 GeV ions at 10^{-8} Torr gives 3% loss),
6. The chamber has to be cleared after the shot and chamber conditions for the next shot have to be reestablished.
7. Power conversion system has to capture and transfer nuclear power and convert it to electrical power.
8. Tritium needs to be bred from lithium, recovered and recycled.
9. Valuable materials from target debris need to be recovered and recycled.

The Robust Point Design and the earlier HYLIFE-II design address most of the requirements listed above. The designs are well documented in the publications and reports.

We started our discussion with a summary of the 2001-2003 Robust Point Design (see Figs. 1 and 2) that made use of a radiation-driven, cylindrical hohlraum target based fairly closely on the NIF target with a few hundred megajoules of yield and about 5 Hz pulse rate. The walls were protected by a system of liquid jets, shown in Figs. 3 and 4. The array of jets was used to protect the beam ports and oscillating jets form the wall protection for a 30-year life of materials. This first wall protection is one of the significant advantages of IFE drivers compatible with thick liquid protection. The final focus used superconducting quadrupoles and dipoles. The magnets were cooled in common cryostats, shown in Fig. 2. Other target designs with one or two compact groups of beams would have a similar chamber design. However, when the yield approaches the GJ range, the pulse rate can be reduced to 1 Hz range. At this pulse rate, gravity can be relied upon for chamber clearing. Therefore, the chamber designs such as waterfalls (HYLIFE-I) can be considered for liquid wall protection. However, for high output per pulse designs it may be necessary to increase the radius of the chamber. Multiple chambers and large total power still have similar chamber considerations as the Robust Point Design even though the beams might be of much higher kinetic energy and therefore fewer individual beams are used for target illumination. Having fewer beams is an advantage for there is less likelihood of neutron escape.

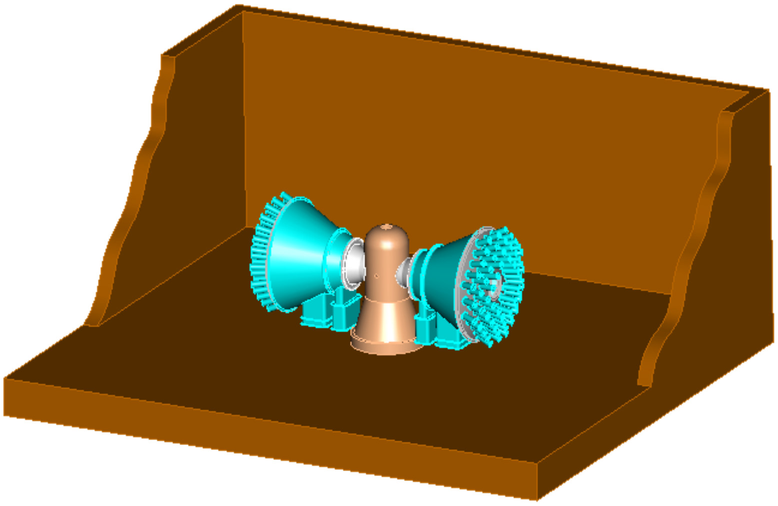

Figure 1: An isometric view illustrating the configuration arrangement of the Robust Point Design (RPD-2002) for a Heavy Ion Power Plant. To give scale the chamber and its final focal system are shown in the ITER building approximately 75 m long.

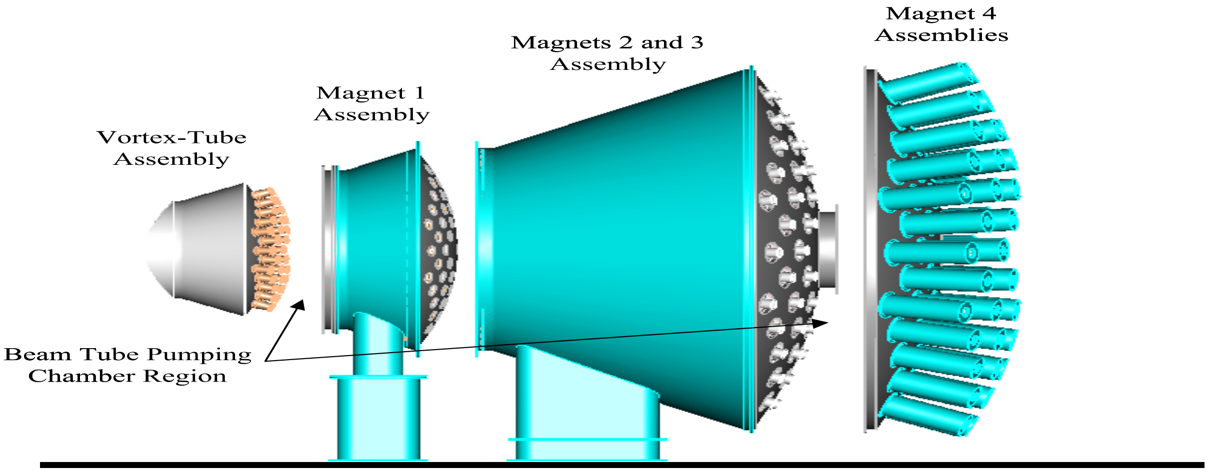

Figure 2: Magnet Assembly Overall Design Philosophy: quadrupole magnets are located in common cryostats. One cryostat structure houses magnet 1 quadrupole and a second cryostat contains magnets 2 and 3 quadrupole assemblies and another magnet 4. The final focus magnet is 6 m from the target and the array shown above is 10 m long. Intermagnet supporting structure is used to align and support magnets 1, 2, 3 and 4 plus add to the overall shielding requirements**.** The current design assumes that a complete final focus magnet section is replaced if maintenance is required**.**

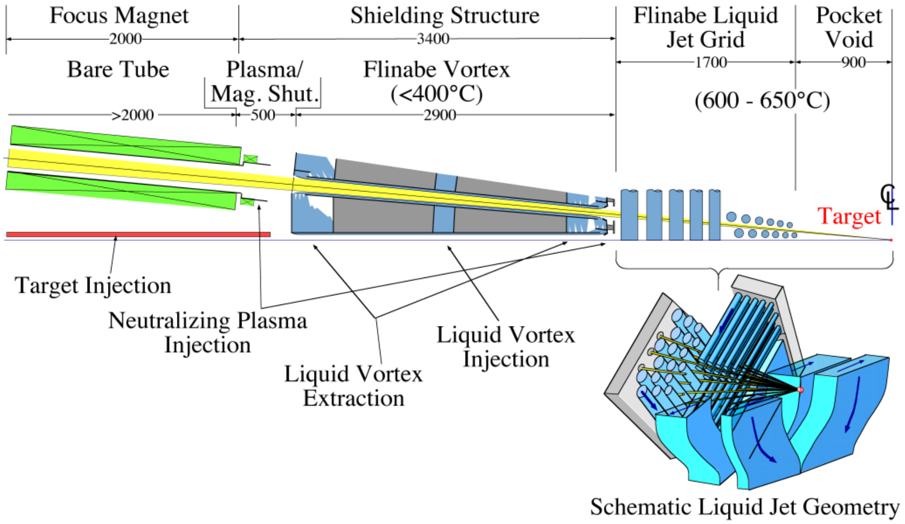

Figure 3: The Robust Point Design (RPD) beam line and schematic of liquid jet geometry.

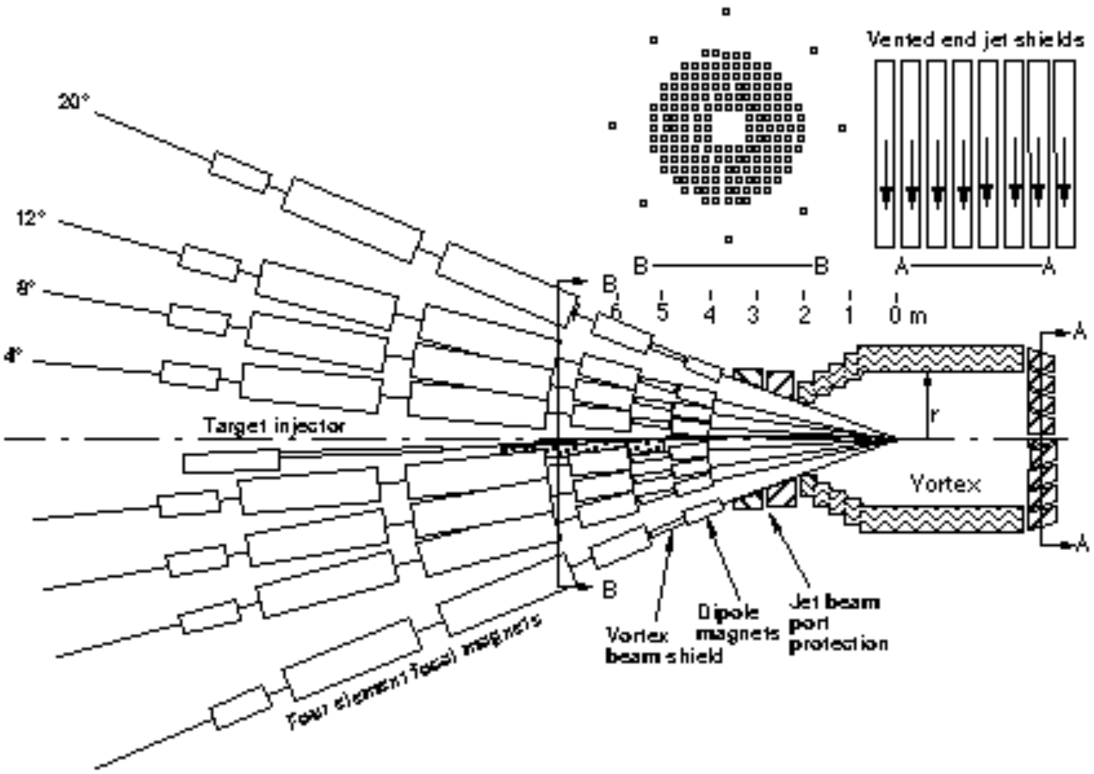

Figure 4: Vortex chamber and beam layout for the X-target. The final dipole bends the beams slightly.

In the RPD design the "pocket" is cleared of liquid debris after a shot by oscillating jets. Close fitting jets protect the beam ports from neutrons. A liquid vortex around each beam line with cooler molten salt reduces the vapor pressure. Shutters, included in the HYLIFE-II but not shown in RPD design have to be installed to prevent much of the vapor from entering the focal magnets. Plasma sources at each end of the vortex would provide electrons to neutralize the space charge of the beam passing to the target. A small dipole magnet and electrostatic electron clearing system, not shown, would prevent electrons from entering the focal magnet system. The final focus system and chamber interface shown in the prior four figures have been worked out in considerable detail and are well documented in publications.

High-level Interface Issues

Thermal management

Cold 4 K magnets must be insulated from hot 400^0 C Flinabe. Neutron and other radiative fluxes must be minimized to prevent quenching of the superconducting magnets or final focus elements need to be made from non-superconducting material. Hydraulics were studied in the water jet experiments at UC Berkeley and elsewhere.

Vacuum management

The vapor pressure in the target chamber, p $\sim10^{-3}$ Torr ,needs to be isolated from high vacuum in the beam lines at $\sim10^{-8}$ Torr. Debris from target must be kept out of beam lines. The effective solution is adding a mechanical shutter and the vortex with <400 °C molten salt with its lower vapor pressure.

Mechanical support

Due to pulsed power the structures are subject to large mechanical stresses. In addition, quadrupole magnets interact with each other. The mechanical support structure has to be designed to withstand these stresses. Reduction in size of the final focusing array is highly desirable, and opportunities to achieve this were discussed.

Radiation management

Magnets must be shielded for 30-year lifetime. Nuclear heating of the superconducting magnets must be as low as possible. Neutron loss to the external environment must be minimal. Studies by Latkowski showed the neutron damage lifetime of the magnets was over three decades.

Magnet alignment

Beam alignment must be maintained within less than 1mm. This requires magnet alignment and active correction with pulsed dipoles.

Maintenance and Assembly

The target and beam array design should allow power production in the event of the loss of a few beam lines. Failed beam lines have to be replaced in less than 6 months.

Utility Feeds management

Magnets are closely packed. This presents a challenge for providing utility feeds for cryogenic system, magnet power, instrumentation lines, and Flinabe lines from all of the ~100 beam lines.

The recommendations of the chamber and chamber driver interface group

A program on chamber and chamber driver interface R&D is recommended including one or more *multidisiplinary* HIF design studies of an integrated HIF power plant based on the RPD or similar illumination geometry and include new facilities to address chamber issues.

The study should develop complete baseline scenarios of simultaneous compression and focus of intense beams to target including resolution of uncertainties, optimization of the system, analysis of errors and misalignments, effects of beam stripping in collisions, gas desorption form the walls, imperfect neutralization of beam space charge and current with care being taken to examine alternatives that might relieve constraints inherent in the RPD configuration.

The current RPD chamber was designed specifically for an induction linac driver. However, it could be used for other driver configurations such as an RF driver with similar illumination required by the target. One of the RF driver systems ("single-pass") shown at the workshop had a much higher kinetic energy. The induction driver could have had a higher energy if desired. The target for the single-pass RF system's chamber would only need to have a total of eight entrance beam ports, a tremendous simplification of the design that affects neutron containment, maintainability, and operational reliability. And it would need to be larger in diameter for conceptual RF systems have energy release per pulse that is significantly higher. The added wall damage effects of these higher yield pulses could be strongly mitigated by the intervention of the Lithium or Flibe or Flinabe jets and droplets typically of cm dimensions but a radius increase of perhaps 30 percent might be needed. A program to examine alternate uses of the RPD concept seems warranted.

The study should encompass the following:

- Perform a comprehensive survey of current status of knowledge on liquid wall designs for chamber, neutralization sources, beam neutralization requirements, and a tolerable momentum spread of the beam for focusing.
- Explore combinations of electrostatic and magnetic quadrupoles for achromatic focusing.
- Develop designs with thick liquid walls, including a liquid vortex with no moving parts with 50-year lifetime and reduced pumping power, and conduct fluid dynamic experiments to validate designs.
- Design rotating shutters to keep debris out.
- Study plasma sources for neutralization capable of working in a neutron radiation environment
- Include dipoles to steer the beam to the target.
- Perform comprehensive optimization of the final focus design for the HIF driver, including:
    - Study of beam pulse shaping with different individual beam pulses, each shaped in time.
    - Study of design with larger-radius beam spots allowed at the target. This would allow easier focusing and thus smaller beam aperture in the final focus.
    - Reconsider higher beam kinetic energy and reduced number of beams.
    - Consider elliptical holes in a shield for the final focus magnets instead of circular. This is more consistent with the beam shape.
    - Design array of final focus magnets with magnetic flux sharing to achieve a closely-packed array of beams. This would allow much reduced shielding.
    - Consider different materials for the final magnet, including normal conducting materials based on new recently developed materials to reduce the size of the magnet array.

It was noted that the proposed study requires many large scale simulations to be performed preferably in three dimensions, demanding for further development of three dimensional codes for beam-plasma interactions including robust support for code development, benchmarking, maintenance, and user support.

Although much of the discussion centered on designs from US induction-linac HIF research programs, an effort should be made to broaden the opportunities for other and international institutions to participate in the recommended programs. Future programs should enable cooperation with partners where different systems approaches exist (e.g., RF systems).

The requirements of chambers compatible with an RF accelerator should be examined. The basic RPD design may be appropriate if the number of ports is reduced to 4 from each of two sides. This would greatly reduce the neutron radiation loss and fewer ports would allow a 'dog-leg' in each beam entry system that would assist in neutron control.

Summary

The RPD-2002 configuration was in an early stage of development. Further study should include many more design details, machine options and system trade-offs to make a full assessment.

Maintainability issues need to be fully understood from the standpoint of component activation and personnel access.

Total radiation loss from the beam ports needs to be examined with the goal being a better means of shielding or reducing the solid angle subtended by the beam entrance ports.

Design details of the beam tube pumping must to be developed to assure vacuum requirements are met.

The details of the beam matching and steering magnets, plasma sources, and shutters will affect the assembly process; consequently their integration into the design is needed.

References:

R. W. Moir, et al., "*HYLIFE-II: A Molten-Salt Inertial Fusion Energy Power Plant Design—Final Report,*" *Fus. Technol.* **25** (1994) 5-25.

The following three references describe the "Robust Point Design"—

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