Emerging Concepts Reactor Subgroup Summary

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Emerging Concepts offer unique reactor features, which may lead to a qualitative improvement in cost and maintainability, with associated increased attractiveness to the customer. Table 3 shows some of these unique features grouped by concept:

Concept	Motivation
RFP	Low external field; no disruptions
Spheromak, FRC	Simple geometry; small size; open axial divertor
MTF, Flow Pinch	Low development cost; compatible with liquid walls
Levitated Dipole, Centrifugally confined	High β, classical confinement; no current drive
Mirrors	Low physics risk; linear geometry
Electrostatic, IEC, POPS	Small unit size; low-cost development; high mass power density; alternate applications
Fast Igniter	High gain; low recirculating power

Table 3: Reactor features of Emerging Concepts.

Again, many examples of reactor advantages associated with Emerging Concepts could be given. As one such, there appears at first examination to be a greater accessibility for incorporating liquid walls into many such reactors. This follows from the linear, open geometry of several of the concepts, including FRC, MTF, Flow Pinch, and Mirrors.

Organization

The reactor subgroup, jointly with the Physics subgroup, heard presentations arranged before the conference on the 11 concepts listed below. These covered a wide range in physical parameter space with radically different reactor embodiments. The reversed field pinch and spheromak talks were held jointly with the Magnetic Confinement sessions. For each concept, a presenter introduced the concept and reviewed progress to date and important physics and reactor issues. The presenter was followed by a reviewer who brought additional insights.

Concept	**Presenter**	**Reviewer**
RFP	S. Prager	K. Schoenberg
Spheromak	B. Hooper	M. Yamada
FRC	A. Hoffman	R. Majeski
MTF	R. Siemon	J. Hammer
Dipole	J. Kesner	M. Schaffer
Mirrors	D. Ryutov	D. Baldwin
Centrifugal Trap	A. Hassam	H. Strauss
Electrostatic	D. Barnes	W. Nevins
Ion Rings	J. Greenly	J. Finn

Flow-through pinch	C. Hartman	A. Glasser
Cross-section enhancement	J. Perkins	L. Bromberg

Additional concepts were discussed at the meeting with presentations on the following:

Fast Igniter	R. Stevens
Pycnonuclear Fusion	S. Ichimaru
Propagating Burn Z-Pinch	F. Winterberg
Tandem FRC	J. hammer
Linear/Toroidal	A. Sen
Self-generated B Fields	T. Dolan

Speakers were asked to consider the following elements in preparing their talks:

1. A brief discussion of the physics principles of the reactor concept.
2. A set of the most important parameters for a fusion reactor based on the concept (geometrical parameters, magnetic field strength, neutron/heat wall load, average electric power, recirculating power, pulse rate for pulsed reactors, requirements to the power supply systems for pulsed reactors.)
3. A summary of what has already been well established experimentally and theoretically.
4. A list of key physics issues which are still unsolved or where significant uncertainties remain.
5. A list of main unresolved technology issues.
6. A list of the main existing (or once existing) experimental facilities exploring the concept (including non-U.S. facilities.)
7. The suitability of the concept for alternative fuels.
8. Thoughts on possible technology breakthroughs that would have the strongest impact on the concept (e.g., new materials, new magnets, etc.), or alternately, the possible technological spin offs that could be generated by research on the concept.
9. A description of the next logical step in the development of the concept or, for more mature concepts, a sketch of the development path to a reactor. What is envisioned for the next step (ie. upgrades to present facilities or entirely a new facility)? What critical physics issues would be addressed by the next step? What would be reasonable metrics for the next step?
10. At what level of performance is moving to the next step justified? What experiments or theory are being done to address these issues?

It was understood that some of the topics were not applicable to every concept.

Reactor Issues

The primary motivation for pursuing Emerging Concepts is the potential for a qualitatively improved reactor product, but of course many uncertainties exist given the early stage of physics understanding and limited technological development in most cases. Some of the perceived advantages and possible technological challenges for the various concepts were discussed and are listed here.

Reversed Field Pinch. The Reversed Field Pinch (RFP) offers the potential of higher β, and hence higher power density and lower size and cost than a conventional tokamak. Additional technological issues that would affect a reactor realization include current drive and feedback stabilization of MHD modes on the resistive skin time of the conducting shell. Scaling of confinement to the reactor regime is another issue that could affect the minimum size and total power of the device.

Spheromak. Spheromak reactors would be similar to an RFP reactor in character, i.e., the technological advantages and issues are similar to those noted for the RFP. A significant additional advantage, however, is the absence of a center post, which simplifies the coil geometry and provides a natural divertor region along the spheromak geometric axis. The fluctuations and accompanying enhanced transport associated with magnetic relaxation during current drive may force the Spheromak to pulsed rather than CW mode. In pulsed mode, the Spheromak may be a candidate for compression with a liquid liner, as in the Linus concept. At higher energy density, compression could be effected on microsecond time scales with a solid liner, i.e., as in MTF discussed below. As already noted, devices with non-toroidal coil topology such as the spheromak appear more naturally adapted to liquid first walls.

Field Reversed Configuration. Field Reversed Configuration (FRC) reactors could represent the ideal magnetic fusion reactor if the physics can be successfully scaled to the reactor regime. The FRC possesses all of the benefits of the Spheromak, i.e., simple coil topology, natural divertor and possible compatibility with compression or liquid walls, with the added benefit of very high β (~1), which leads to high power density at modest field strength. Uncertainties exist as to the minimum size needed for adequate confinement and the technological requirements to sustain the current, e.g. with rotating magnetic fields, and maintain stability when the FRC is many gyro radii across, e.g., with flow shear or energetic particles.

Magnetized Target Fusion. Magnetized Target Fusion (MTF) offers a qualitatively different pathway to fusion with potential for a much shorter and less expensive development scenario. MTF seeks to compress magnetized fuel to high density and high β with a solid liner, or at somewhat reduced energy density with a liquid liner. Fusion quality plasmas may be accessible at modest energy, enabling near term experiments to take a significant step along the development path. There are many potential target plasmas, e.g. FRCs or Spheromaks as discussed above. Physics issues such as convective cell transport or mix of high Z contaminant from the liner may prevent access to the high temperature regime or place constraints on reactor technology such as inclusion of magnetic shear in the fuel to suppress convection, or requiring low Z liners that reduce the available energy density. Standoff of the target from the energy source, e.g. with disposable electrodes, is a major cost and technology issue.

Levitated Dipole. Levitated Dipole reactors have the potential for high β, possibly classical confinement (if convective cells can be suppressed), no neoclassical degradation of confinement since the toroidal field is zero, and a simple external coil set, with the exception of the levitated ring itself. No parallel current drive is required.

Technological issues include the sustainment of a superconducting ring internal to the plasma, and the likely requirement for aneutronic fusion fuel.

Centrifugal Confinement. Centrifugal Confinement reactors are potentially high β, high power density devices without toroidal field that require no parallel current drive. The external coils are of the axisymmetric mirror type, and the simple magnetic topology may be compatible with liquid walls. Technological challenges include the employment of high voltage insulators in a reactor environment and the power required to sustain the azimuthal flow.

Mirror/Gas Dynamic Trap. Discussion focused on the Gas Dynamic Trap (GDT), i.e., a collisional mirror machine. The unique advantage of a GDT reactor among the Emerging Concepts is the low physics risk, since it is based on well-established principals. The GDT also has the advantage of simple, linear magnetic geometry. The primary disadvantage is the large unit size required to reach adequate axial confinement.

Electrostatic Confinement. Electrostatic Confinement could lead to a highly modular reactor with high mass power density and low wall loading. The modularity allows especially low development cost. Small electrostatic confinement cells would be linearly stacked and grouped in parallel arrays similar to fuel rods in a fission reactor. Issues include the RF power requirements to sustain the oscillating potential (so called POPS mode), which leads to a large recirculating power fraction. The RF coupling requires insulators within the reactor environment. Electrostatic confinement is the only fusion concept that can boast of near term applications, viz., as a neutron source for medical isotope production and well logging.

Ion Rings. Ion Rings are closely related to the FRC and may serve as the stabilizing agent in an FRC reactor. Non-thermonuclear, colliding ring systems provide a simple reactor embodiment but suffer from very low Q. Co-rotating large orbit rings that are thermonuclear in the rotating frame avoid this problem, although formation, ring energy loss, and spread remain issues.

Flow through Z-Pinch. The Flow through Z-pinch offers the reactor advantages of simplicity, high β, low cost, and high power density. Issues include the end loss power, which in turn is affected by the minimum flow velocity required for shear flow stabilization, and electrode erosion.

Fast Igniter. The Fast Igniter inertial fusion concept could improve IFE reactor attractiveness by significantly reducing the minimum driver energy and by relaxing the requirements on implosion quality, which could reduce the cost of targets. Fast ignition can also greatly increase the target gain, thereby lowering the recirculating power or permitting use of a less efficient but potentially cheaper driver.

Cross section enhancement is not sufficiently well characterized to evaluate reactor possibilities, with the exception of muon catalysis. For cross section enhancement, the reactor benefits would likely be dramatic if a successful, i.e., net energy producing scheme, can be found.