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HYLIFE-II Inertial Confinement Fusion Reactor Design

Ralph W. Moir

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Ralph W. Moir

University of California
Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, California 94550

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Abstract

The HYLIFE-II inertial fusion power plant design study uses a liquid fall, in the form of jets to protect the first structural wall from neutron damage, x rays, and blast to provide a 30-y lifetime. HYLIFE-I used liquid lithium. HYLIFE-II avoids the fire hazard of lithium by using a molten salt composed of fluorine, lithium, and beryllium (Li_2BeF_4) called Flibe. Access for heavy-ion beams is provided. Calculations for assumed heavy-ion beam performance show a nominal gain of 70 at 5 MJ producing 350 MJ, about 5.2 times less yield than the 1.8 GJ from a driver energy of 4.5 MJ with gain of 400 for HYLIFE-I. The nominal 1 GWe of power can be maintained by increasing the repetition rate by a factor of about 5.2, from 1.5 to 8 Hz. A higher repetition rate requires faster re-establishment of the jets after a shot, which can be accomplished in part by decreasing the jet fall height and increasing the jet flow velocity. Multiple chambers may be required. In addition, although not considered for HYLIFE-I, there is undoubtedly liquid splash that must be forcibly cleared because gravity is too slow, especially at high repetition rates. Splash removal can be accomplished by either pulsed or oscillating jet flows. The cost of electricity is estimated to be 0.09 \$/kW·h in constant 1988 dollars, about twice that of future coal and light water reactor nuclear power. The driver beam cost is about one-half the total cost.

Introduction

The HYLIFE-I design (Blink et al., 1985) in which a molten salt composed of fluorine, lithium, and beryllium (Flibe) is substituted for liquid lithium is called HYLIFE-II (Moir et al., 1990). It will work with minor modifications of the HYLIFE-I design (e.g., beam access) if targets having a yield of 1.8 GJ (a gain of 400 with a 4.5-MJ driver) can be obtained, as assumed in HYLIFE-I. Splash clearing, however, was never satisfactorily accomplished in HYLIFE-I. High gain (400) results from advanced targets and is beyond the state-of-the-art. Conventional targets are predicted to have gains of 70 at 5 MJ with projected beam parameters giving a yield of only 350 MJ. Such low yields (350 MJ rather than 2000 MJ) push the design to high repetition rates to obtain either the same power or higher driver energy and result in major departures from the HYLIFE-I design. Because, for any target design, the gain increases with driver energy, a larger yield can be obtained with higher driver energy, but drivers are expensive and the cost increases as the driver energy increases. The cost of electricity is expected to decrease as the repetition rate increases and eventually to rise again when pumping power becomes large. We find this rise is above 10 Hz. We looked at three ways to obtain a higher repetition rate: use three chambers, pulse the flow, and use oscillating nozzles.

Flibe Compared to Liquid Lithium

The lithium fire hazard in HYLIFE-I will be eliminated by using the low-viscosity molten salt, Flibe (Li_2BeF_4). Flibe can operate compatibly with Hastelloy N or 316-stainless steel at a much higher temperature than lithium (923 K vs 770 K). The heat-transfer properties, while different, should remove heat and serve the purpose of a liquid protecting the permanent structure from neutron damage and blast. Because it is not a single element like lithium, dissociation may slow condensation and limit the repetition rate. There is also a potential corrosion problem from fluorine compounds formed during the evaporation process.

Plant Parameters

The plant parameters for the base case using pulsed flow (Hoffman, 1991) are shown in Table 1. The power balance diagram is Fig. 1. System studies are underway to vary the driver energy, thus changing the repetition rate. The driver cost should drop as repetition rate increases, if the gain does not drop too fast with the increasing repetition rate. We have shown the cost of electricity falls rapidly as the repetition rate increases from 1.5 Hz to about 4 Hz. There is very little further cost decrease as the repetition rate increases from 4 Hz up to our design point of 8 Hz. A key concern is the pumping flow rate (Table 2). We have reduced the flow rate from the 96 m^3/s of HYLIFE-I to 66 m^3/s and the liquid inventory from 1600 m^3 to 750 m^3. However, the density of Flibe is four times that of lithium and we should try for further reductions. By decreasing the radius to the first wall from 0.5 m to 0.3 m and decreasing the flow speed, the flow rates and inventories might be further reduced, thereby lowering the costs.

Table 1. Plant Parameters

Driver energy	5 MJ
Target gain	70
Yield	350 MJ
Blanket multiplication	1.15
Repetition rate	8.2 Hz
Fusion power	2835 MW
Thermal power	3312 MW
Recirculating power	282 MWe
Pumping power	37 MWe
Beam electrical power	203 MWe
Auxiliary power	42 MWe
Net electrical power	1083 MWe

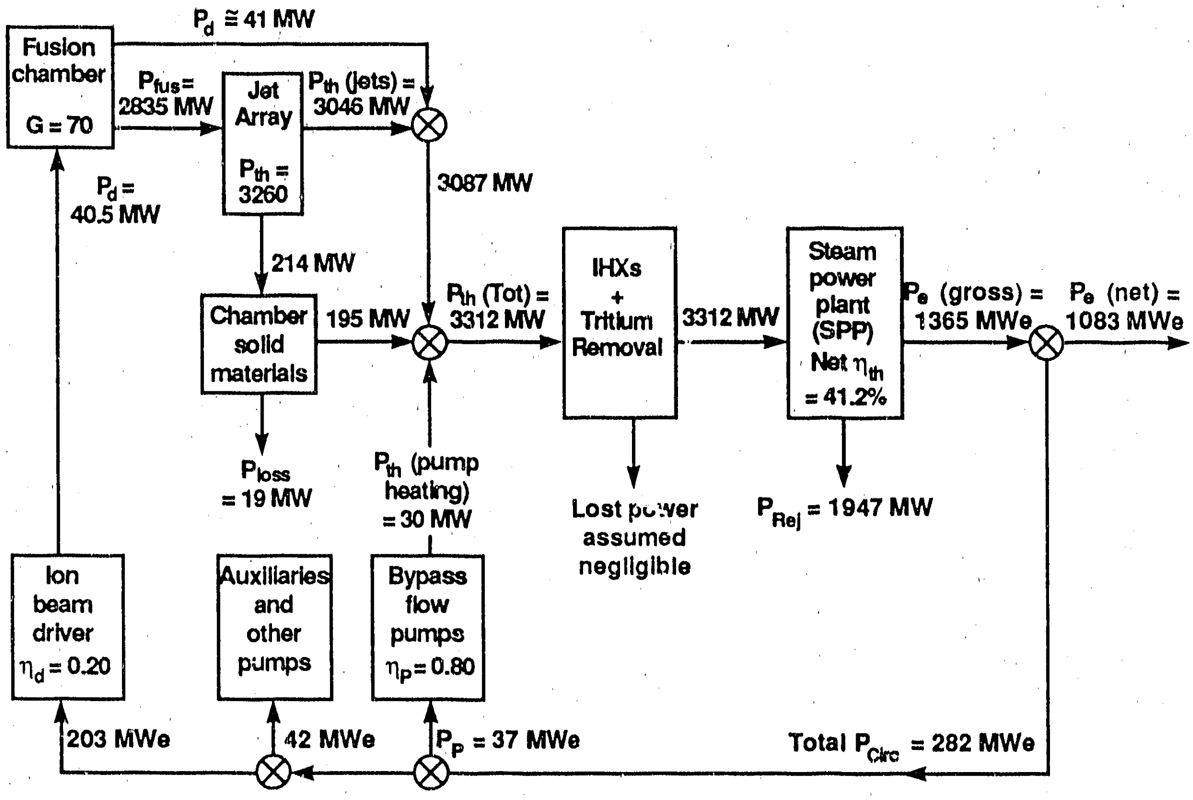

Fig. 1. Detailed power balance fo the base case HYLIFE-II.

Table 2. Jet Array and Primary Loop Param^eters.

No. of chambers		1
Fall distance between shots (m)		2.1
Repetition rate (Hz)		8.1
Injection velocity, V_0 (m/s)		16.2
Static head required to produce V_0 (m)		13.4
Vol. flow rates (m^3/s):		
Jet array (bypass flow)		53.6
Spray (max.)		9.7
First wall		2.6
Total Flow		65.9
No. of main pumps (rated flow per pump = 5 m^3/s):		
Bypass flow		11
IHX flow		3
Method used to produce V_0	Static head	Press. pipes
Bypass pumping power (MW_e): (for η_p = 80%)	~37	~37
Bypass pump head		
Gravity head above pool (m)	19.8	10.4
Friction + minor losses (m)	7.5	16.7
Total pump head (m)	27.3	27.1
Bypass pipes: inner diameter (m)	1.0	1.0
Estimated total Flibe inventory (m^3)	960	750

Target

The target is designed for heavy ions such as $^{200}Hg^+$ at 10 GeV. The gain depends on energy delivered to the target, beam radius (2 mm), and ion range (0.1 g/cm^2). Target gain curves for a zero-degree beam half angle are shown in Fig. 2a (Bangerter, 1991). We assume 30% of the energy, 5 MJ for example, is delivered on a long "foot" pulse of about 30 ns and 70% is delivered in the main pulse lasting about 8 ns. If the beam half angle is ±13° then the gain is reduced by 19% (Fig. 1b) (Moir et al., 1990). To obtain a yield of 350 MJ will require about 6 MJ input energy (as can be worked out from Fig. 2 for a range of 0.1 mg/cm^2 and 2 mm focal spot size). The correction for beam angles leading to the 6 MJ driver were not incorporated in the rest of this work. The design work did not consider the target factory, target injection, and tracking.

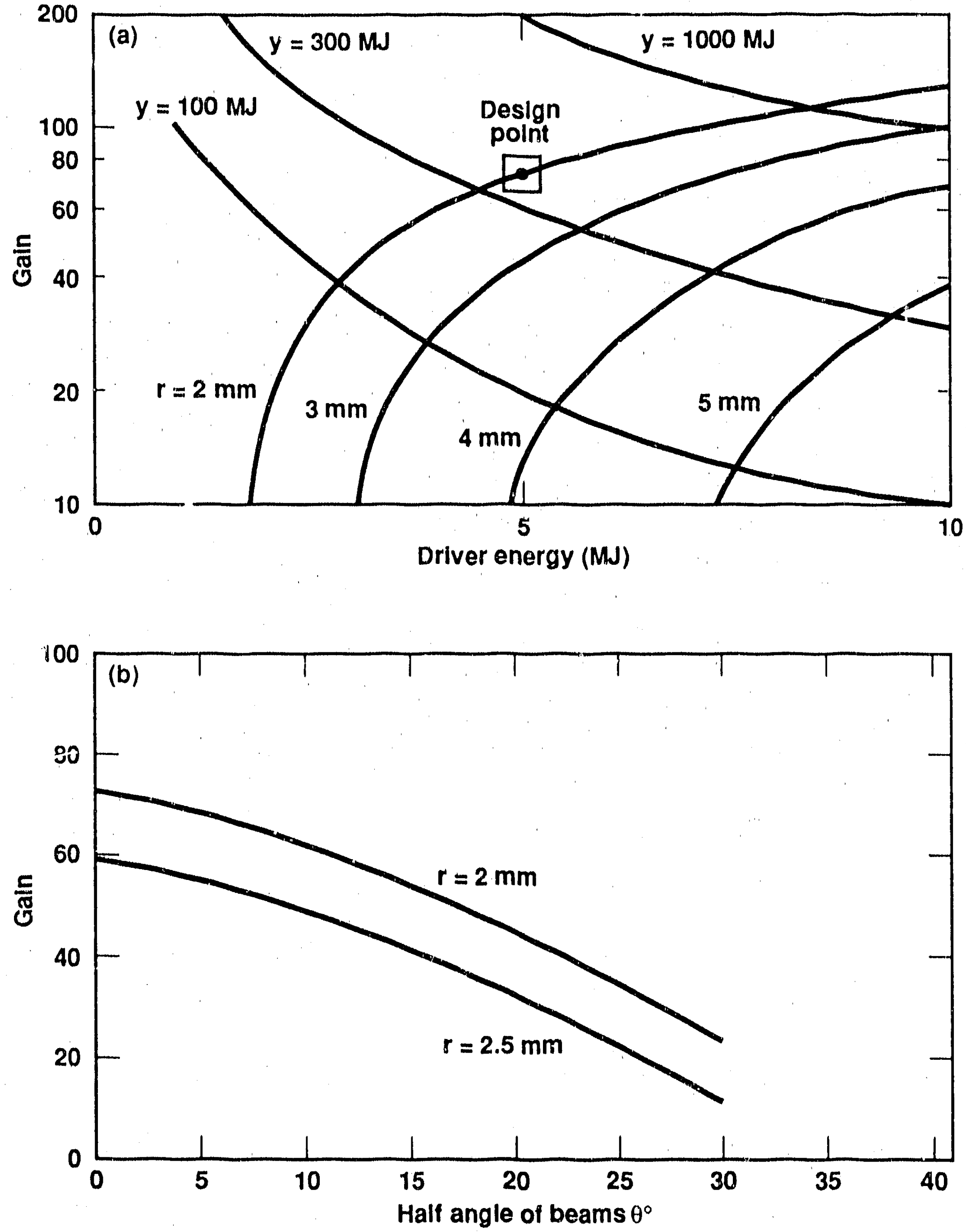

Fig. 2. Target gain vs driver energy and beam half-angle. The beam spot size r and range R are given as parameters. The design point is 5 MJ, gain 70, range 0.1 g/cm^2, and spot radius [illegible]. The beam angle of about ±13° has yet to be put into the analysis.

Driver Interface Issues

The driver is assumed to be a heavy-ion beam, although we also considered laser and compact-torus drivers. Because energy in a single beam is limited, 16 separate beams are assumed to provide the nominal 5 MJ total energy. These can be directed from two sides of the reactor or from only one side. The difficulty is to get a close-packed array with enough shielding. The beams are shown in Fig. 3. A heavy-ion driver at 5 MJ, based on $^{200}Hg^{+}$ at 10 GeV, costs in the range of $1 B to $2 B ($10^9$ $), a factor of 3 or more too high for good economics. Other drivers, such as a recirculating induction accelerator with fewer components are possible. Another possibility is the mirrortron, which has as a goal to shorten the heavy-ion beam lines by obtaining an order of magnitude higher average gradient than is possible with induction accelerators (400 m long vs 4000 m). Compact tori that are accelerated and focused require a much different target and transport system design are interesting because of their order-of-magnitude lower cost (about $100 M). However, they are speculative because the experimental parameters of compact torus accelerators are orders of magnitude away from that needed. Laser drivers have been considered but are not leading candidates at this time because of high cost, low efficiency, and poor target performance as well as the need to illuminate of the target from many angles. Our back-up strategy to cut the driver's contribution to the cost of electricity is to either have one driver switched to up to four reactors, each of 1-GWe size, as done in the HIBALL-II study (Badger, 1984) or to increase the power out of the reactor chamber up to 4 GWe. The cost and complication of switching is probably acceptable when the total power is as high as 4 GWe, but is not acceptable at 1 GWe.

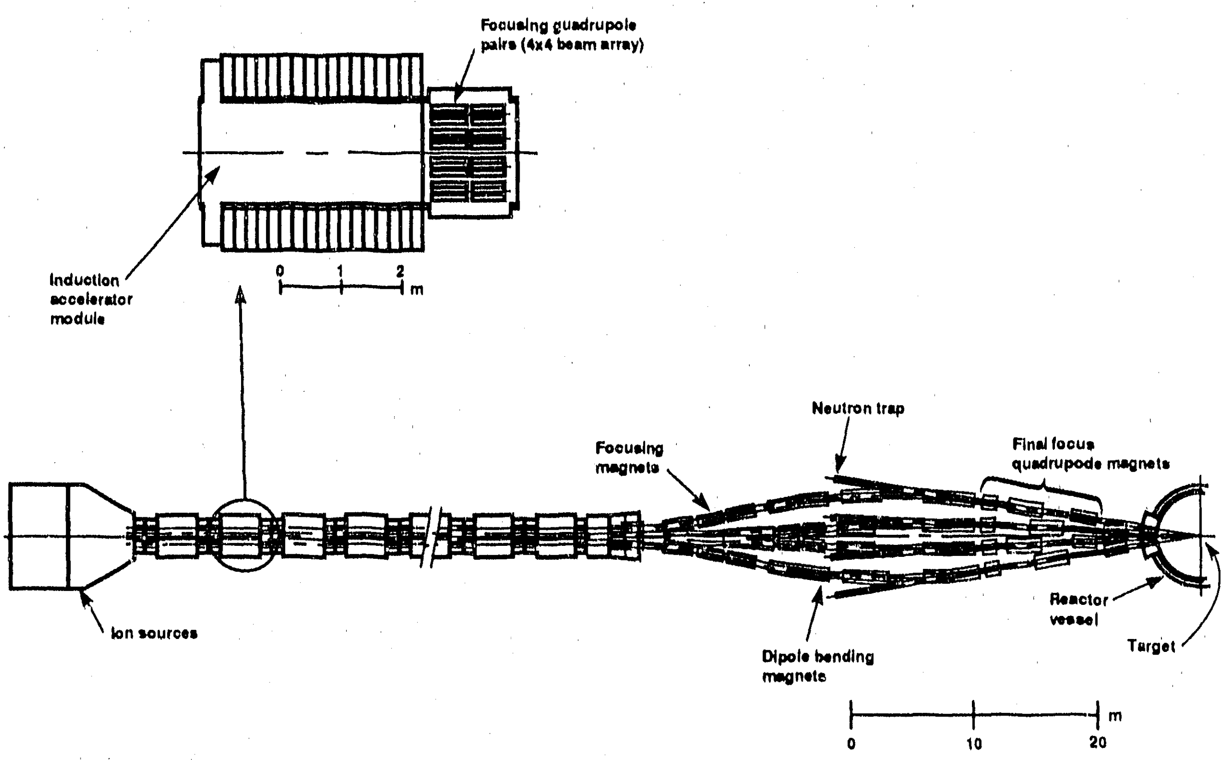

Fig. 3. As an example we show a one-sided configuration of HYLIFE-II with 16 beams using heavy-ion induction linear accelerators. The length is approximately 4 km. The final beam focusing magnets (last 50 m) are in a very preliminary design stage. The half-angle encompassing all beams is ±13° for this 4 x 4 array.

Chamber Mechanical Design

A liquid fall is used to protect the first structural wall from neutron and blast damage. The liquid breaks up as a result of sudden neutron heating and the wall must be strong enough to contain the flying liquid (Chen and Schrock, 1991a; Liu, Chen, Schrock, and Orth, 1991; and Chen and Schrock, 1991b).

Steady Flow with Multiple Chambers

The HYLIFE-I chamber shown in Fig. 4 is a steady-flow chamber. The structural wall is protected by weir flow. This requires slow flow (10 m/s) and a long fall distance (about 5 m) to protect the nozzle parts from neutron damage by the curvature of the flow over the weir. The repetition rate is low (1.5 Hz) because of the long reformation time of the jet array. Splash is only partially cleared by gravity. The large distance above the target (over 8 m) would not be cleared.

To obtain enough power in HYLIFE-II, we considered using up to three 2.7-Hz chambers (1/3 GWe each). This system would have the complication of switching beams, high pumping power, high cost for a 1-GWe power plant, and still not be cleared of splash. The three-chamber design option was so undesirable it was dropped from further consideration.

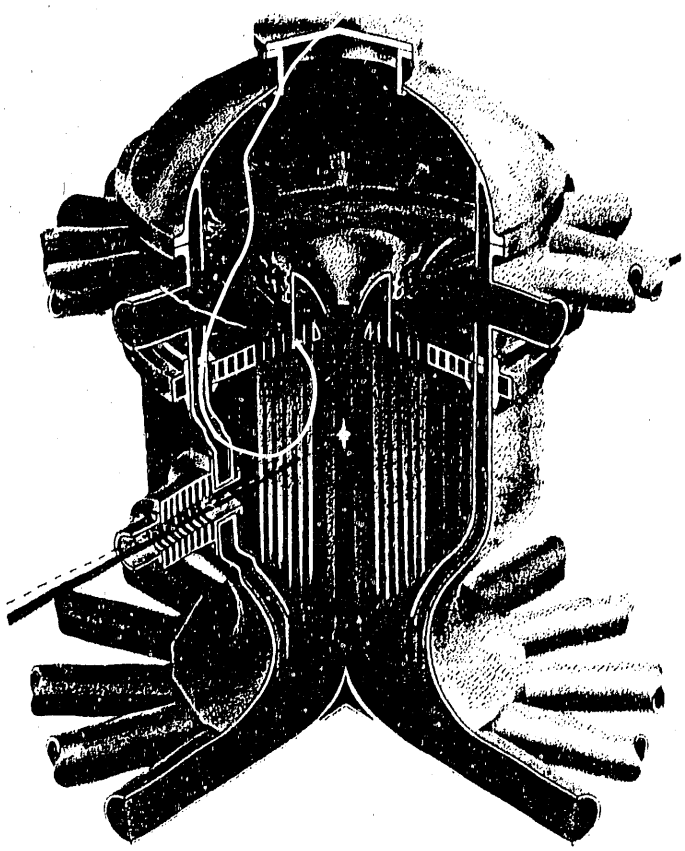

Fig. 4. HYLIFE-I used steady flow.

Pulsed Flow

The pulsed flow case shown in Fig. 5 uses continuous flow everywhere except for a slug of liquid 0.3 m in radius and about 1 m long, injected at 12 to 16 m/s for 6 to 8 Hz. The high repetition rate is achieved by a short fall distance of only 2 m. A pulsed pump to inject the slug needs to be designed and developed to withstand cyclic fatigue. The slug will clear splash from the beam path near the target. It is vital that the trailing edge of the liquid slug be sharply cut off and not leave too many splash droplets in the beam path. Other pulsed jets may be needed to clear splash from the rest of the beam path. One issue that requires solution is the isochoric neutron heating of the top of one slug that reduces its velocity and diminishes the volume for the next shot (thereby possibly limiting the repetition rate to 4 Hz). Many issues need further thought.

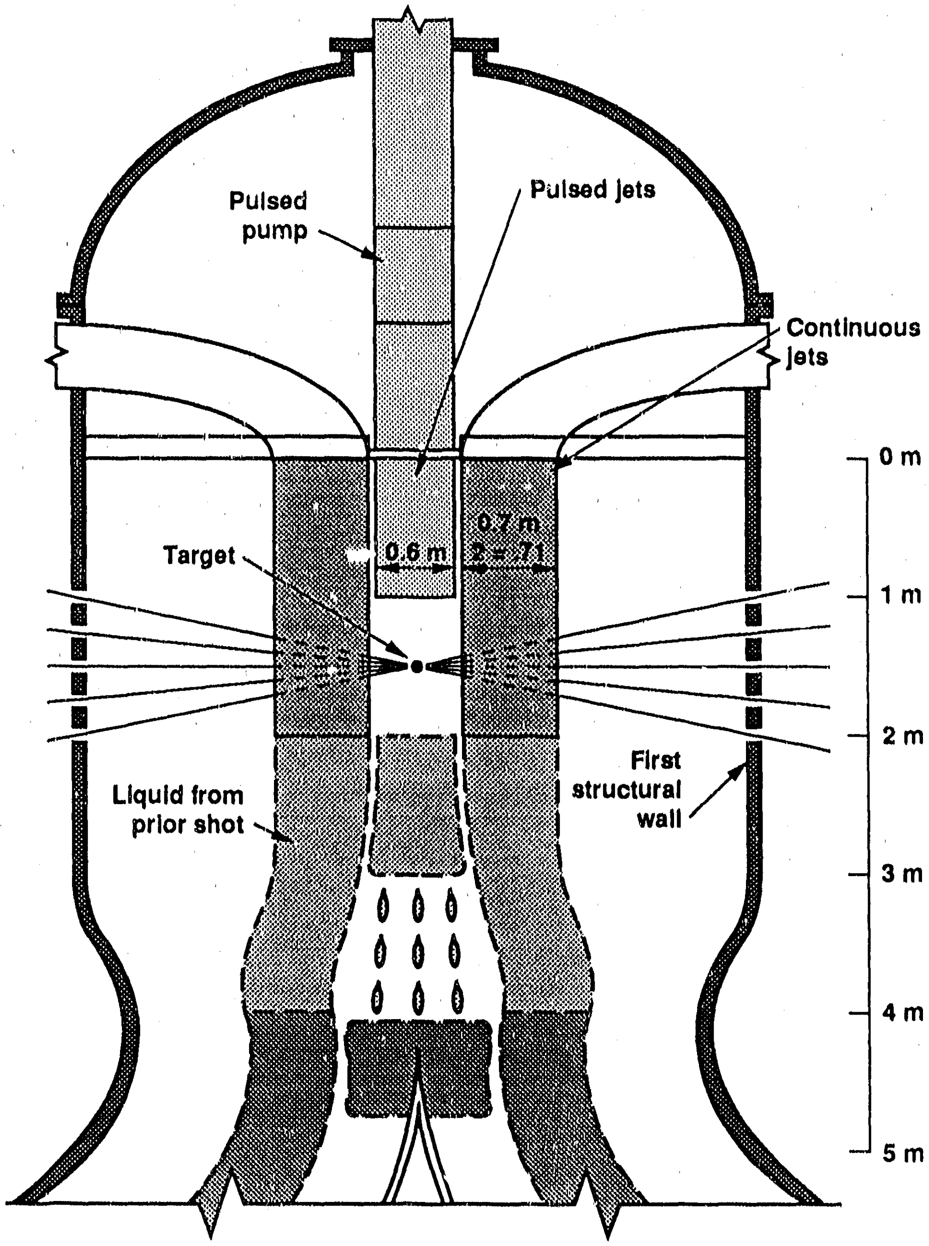

Fig. 5. HYLIFE-II, pulsed flow. The flow speed for 8 Hz is 16 m/s with a 2-m fall height, giving a flow rate of 34 m^3/s.

Oscillating Flow

Another way to achieve a high repetition rate and short fall distance with splash clearing is to oscillate the jet nozzles horizontally, as shown in Fig. 6 (Petzoldt, 1991). A pocket is formed in the flow where a target is injected and the microexplosion occurs. The oscillating flow sweeps splash liquid from the target region. The beam path can be cleared with more oscillating flows or with pulsed flows of liquid. It will be necessary to design mechanical moving parts, including bellows to allow nozzles to oscillate at up to 8 Hz through a motion of up to ±0.1 m. Fatigue and vibration will be design problems.

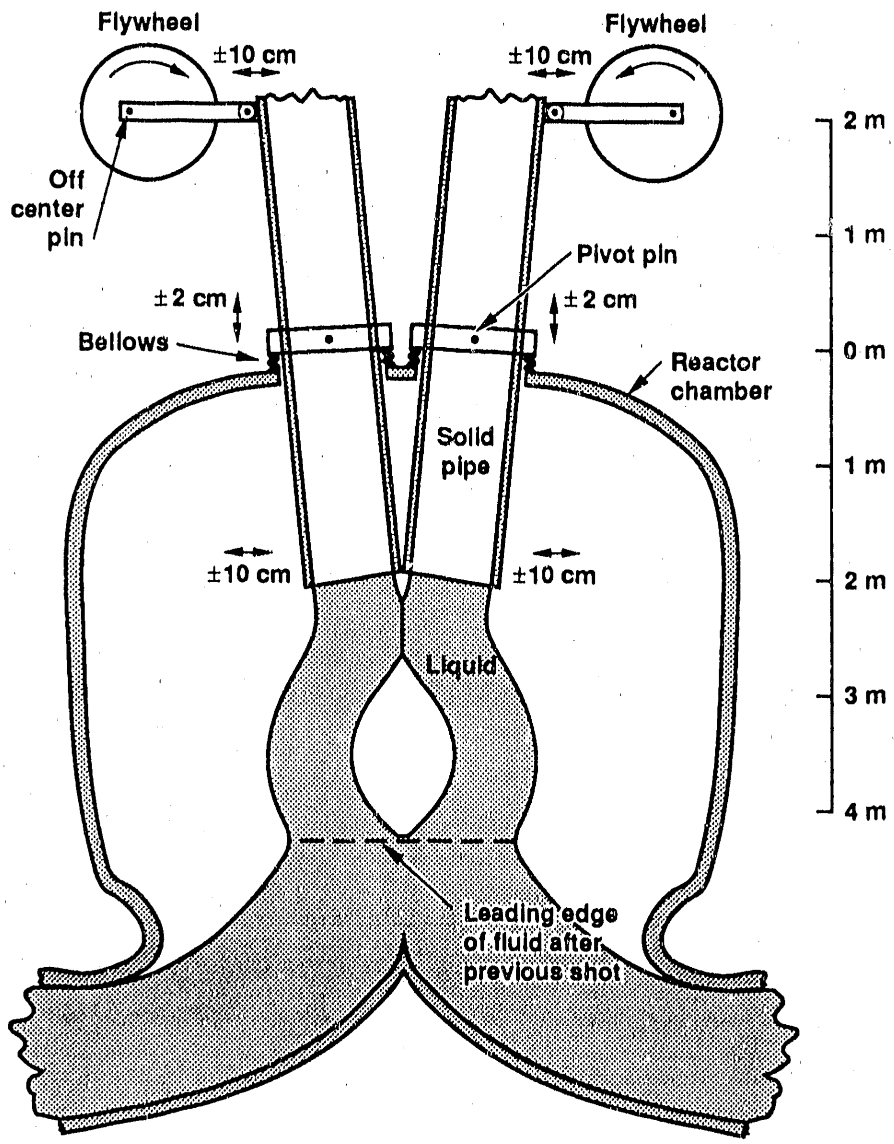

Fig. 6. HYLIFE-II, **oscillating flow.**

Steady horizontal and vertical, neutronically thick, liquid jets shown in Fig. 7 will clear the beam path and protect the beam ports from radiation damage. The spacing between these jets should be less than S ($S = 0.5\ gt^2$), where S is the distance liquid droplets or splash can fall by gravity between shots. For 8 Hz, $S = 7.7$ cm. If splash starts with an upward velocity, the distance S must be cut by up to a factor of two. With this system, splash is not cleared from all regions of the beam.

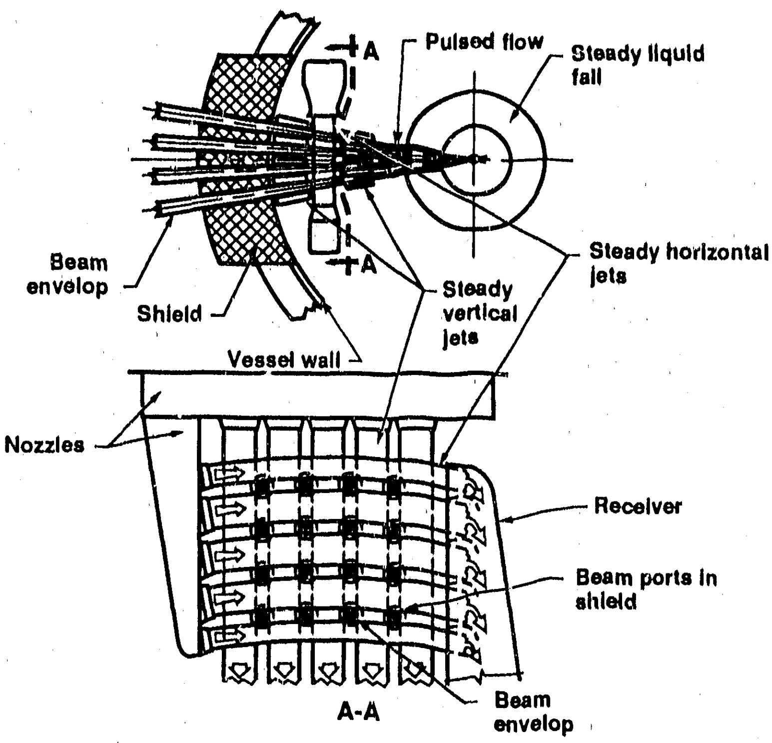

Fig. 7. Thick horizontal and vertical liquid jets protect the beam ports from radiation and help clear splash liquid for the next shot.

Jet Design, Clearing, and Condensation

The energy from the 350 MJ microexplosion will evaporate about 8.8 kg of liquid Flibe. The density of the vapor cloud when it has filled the chamber is about $10^{18}/\text{cm}^3$, assuming 8.8 kg at 5000 K in a 5-m-high chamber with 3-m radius. By the time of the next shot (0.125 s for 8 Hz) the density must drop from $10^{18}/\text{cm}^3$ to about $3 \times 10^{13}/\text{cm}^3$ in 0.125 s for propagation of heavy ions, a factor of 3×10^4. This density reduction can come about by condensation of the vapor on the liquid jets and on the droplets left from the explosion (Bai and Schrock, 1991). One strategy is to inject "cool" Flibe at 873 K in a spray of droplets in the vicinity of the beam paths. According to our calculations, this injected spray can provide enough condensation area without depending on the explosion itself making enough small droplets of the liquid in the chamber. Our present model indicates the temperature in the cloud drops quickly (<< 1 ms) to 5000 K. Below 5000 K, radiation is slow and conduction and convection bring the temperature to about 1500 K when the liquid surface and cloud temperature are equal, after about 1 ms. After this time, condensation proceeds at the rate heat can be transported from the liquid surface into the cool liquid interior. Although we predict condensation will be fast enough to allow an 8-Hz repetition rate, we recommend a definitive experiment on condensation with Flibe because of the complication of condensation of Flibe dissociation products, etc.

Neutronics

Neutronics analyses of the HYLIFE-II reactor concept (Tobin, 1991) includes calculating the tritium breeding ratio (TBR), the system energy multiplication factor (SEMF), the energy deposition in the Flibe and first structural wall (FSW), and the radiation damage rates for displacements per atom (dpa) and helium production. The TBR is 1.17, 1.02 of which is bred in the Flibe fall and 0.15 is bred in the reflector behind the FSW. Nearly 15% of the tritium is bred in ^{7}Li. The SEMF is 1.15, bringing the 2835 MW of fusion power to 3260 MW_t.

Three candidate wall materials were considered for the FSW, two Hastelloys and a modified 316-stainless steel where manganese is substituted for nickel. There is a problem with corrosion of manganese so this option probably will be dropped in favor of unmodified 316-stainless steel. Results show that the 316-stainless steel is a superior choice for helium-generation-limited lifetime, dpa-limited lifetime, and shallow burial index. The areas where the Hastelloy steels are superior include decay thermal power, corrosion resistance, and high-temperature strength. However, the magnitude is insufficient to cause the steel to melt. The main safety issues for HYLIFE-II are the large shallow burial index (106) and the requirement to contain 99.9964% of the ^{18}F inventory to prevent its release to the public. Although fluorine is very chemically active, in the form of Flibe it is well tied up and not volatile. Therefore special nuclear certification as in the ASME (so-called N-stamp) is not needed.

Tritium Systems

Practically all of the tritium gas emitted by exploding targets will be removed by the vacuum pumping system, but almost none of the tritium bred in the Flibe will diffuse out of the Flibe droplets (Longhurst, 1991). At a fusion power of 2835 MWth with a breeding ratio of 1.17, the tritium production rate in the Flibe is 1.16×10^{21} atoms/s. The corresponding radioactivity production rate is 4.8 MCi/d, of which most will be recycled in new targets. The fraction of tritium removed from Flibe by the primary loop vacuum disengager (wherein a fine spray of Flibe droplets permits tritium to diffuse out and be pumped) is about 99%. The fraction of tritium leaking through the intermediate heat exchanger (IHX) per pass of the coolant through the IHX is 6.5%, according to detailed calculations of mass transfer during turbulent flow in the IHX. The fraction of tritium removed from the $NaBF_4$ intermediate coolant by the gas exchanger is greater than 99%. Because data on tritium behavior in $NaBF_4$ are lacking, the fraction of tritium leaking from the $NaBF_4$ through the steam generator tubes is conservatively assumed to be about 1%. For these conditions, the tritium leak rate is held to less than 40 Ci/d, which satisfies the safety goal for routine releases.

The tritium removal system could be very large because the intermediate coolant flow rate is very large. The blast chamber and Flibe piping should be double-walled, to prevent significant tritium leakage under normal and off-normal conditions. Beryllium metal will be used to neutralize free fluorine liberated in the Flibe by nuclear reactions. The greatest need for future work is to design the vacuum disengager and gas exchanger to quantify the size, power dissipation, and cost associated with achieving 99% efficiencies.

Materials and Molten Salt Technology

Compatibility and Corrosion

We chose a high-nickel steel for our vessel material and pipes. A 316-stainless steel will work with adequately low corrosion rates, and modified Hastelloy N (a high-nickel steel) will work even better. In the future we might consider the use of carbon-carbon composites for the vessel material because graphite is compatible with the molten salt if tritium retention is not too serious. Pyrolytic graphite has low retention but porous forms of graphite have higher retention. The use of a graphite vessel will reduce activation, increase tritium breeding, and reduce the heat leak to the shield.

Chemical Kinetics of Dissociated Flibe

We know that when Flibe is dissociated into its constituents by the microexplosion about 9 kg of Flibe is raised to 5000 K. (Recent investigations not folded into this work suggest this temperature may be as much a ten times higher.) These constituents will reform Flibe and not other species. That is, Flibe is stable under radiation and the recombination reaction is strong; however, based on preliminary study, we believe that the recombination is sufficiuently fast not to be a limiting factor in the condensation of Flibe vapor on liquid droplet surfaces. An issue with condensation is that the constituents of Flibe must chemically recombine and stick on striking the droplet surfaces. Too low a sticking ratio will slow condensation. We think LiF will have a sticking coefficient of at least 0.5. We are concerned that the BeF_2 may bounce off liquid surfaces many times before sticking and joining the bulk liquid (sticking coefficient may be 0.01 to 0.05). If the small sticking coefficient is not limiting, we have shown all other processes are fast enough to permit a repetition rate as high as 8 Hz. This is an area for further study and a definitive experiment is needed.

Choice of Target Material

We chose tantalum for use in the target because it is relatively high Z (Z = 72) and is soluble in Flibe. We can make coatings by chemical vapor or liquid deposition. Many other high-Z materials we could have chosen, such as lead and tungsten, would precipitate on the walls of the vessel and pipes, making recovery difficult and causing other problems.

Balance of Plant

The flow diagram of the balance-of-plant (BOP) (Hoffman, 1991) is shown in Fig. 8 The power balance was given in Fig. 1. We have shown the eutectic composition of Flibe that melts at 636 K (363 °C) is practical but costly because of its high viscosity therefore the low-viscosity composition that melts at 733 K (460 °C) was chosen. The intermediate coolant $NaBF_4$ was chosen (based on earlier work at ORNL)(Briggs, 1971) in part because of its tendency to hold up tritium in the form of T_2O and retard its passing on into the steam system and hence to the environment.

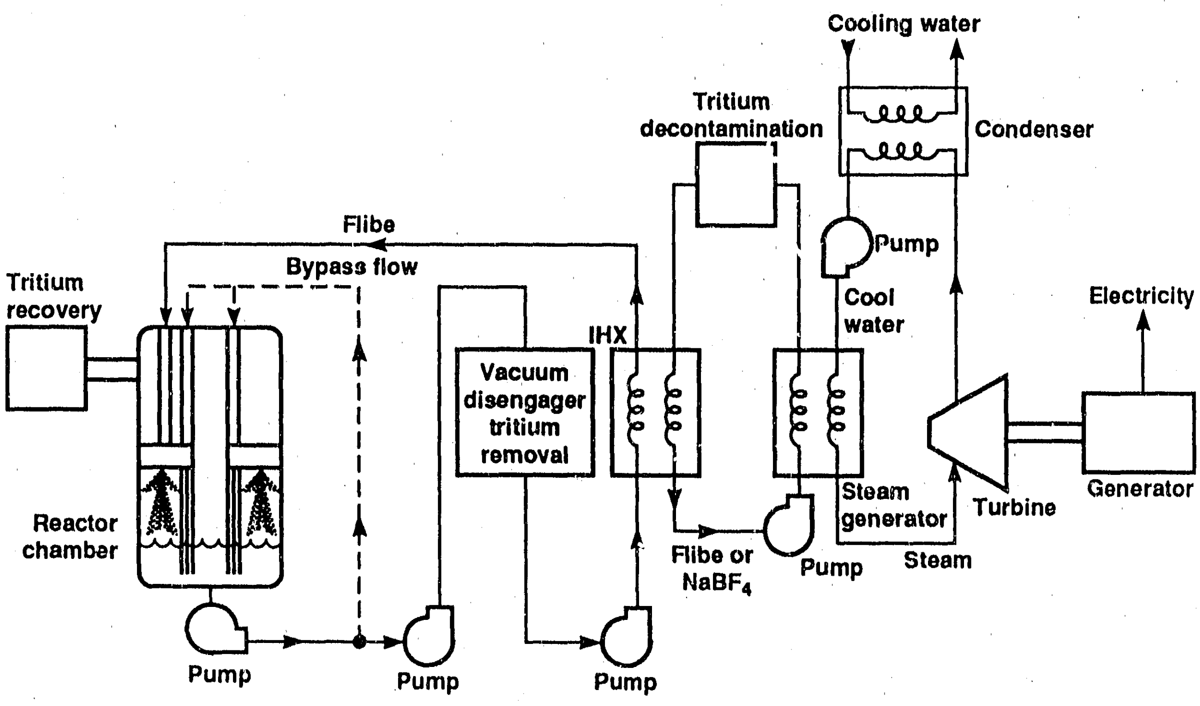

Fig. 8. The reaction chamber and power conversion system for HYLIFE-II.

Safety and Environment

An outstanding feature of the HYLIFE-II reactor is its favorable safety characteristics (Dolan and Longhurst, 1991). Safety and environmental goals for HYLIFE-II include:

- offsite dose from severe accident less than 2 Sv (200 rem) for passive safety,
- no N-stamp requirement for most components, requires less than 0.25 Sv (25 rem) offsite dose,
- working area dose rate less than 50 mSv/h (5 mrem/h) for a low occupational risk,
- dose from routine atmospheric effluents less than 50 μSv/y (5 mrem/y).

To evaluate the potential to meet these goals, the consequences of a severe accident involving blast chamber failure and breach of containment are studied, including the effects of activation products, tritium, and beryllium toxicity. HYLIFE-II has no large sources of energy available to disperse radioactive materials. The tritium inventory in the Flibe could be kept very low (about 1 g). The dominant activation product is about 300 MCi of ^{18}F (half-life 110 m). A very small fraction (6×10^{-6}) of the Flibe activation products would be mobilized, because the microexplosion vaporizes about 9 kg from the 1500 t of Flibe. Only a fraction of the mobilized vapor would escape from a hole in the blast chamber, and only a fraction of that, from a hole in the containment building. The ^{18}F offsite dose from a severe accident (breaching both the blast chamber and the containment) would be less than 0.2 mSv (20 mrem). Thus, N-stamp requirements can be avoided in the main reactor components, and the passive safety goal can be met.

If the maximum vulnerable tritium inventory in the target factory and tritium handling systems were less than 2.5 kg, then the maximum offsite dose from its release would be less than 0.25 Sv (25 rem), and the N-stamp requirement could be avoided for those systems as well. Some contact maintenance should be feasible on the $NaBF_4$ secondary loop, but not on the Flibe primary loop (unless a very effective impurity removal system were operating and activated impurities did not plate out on pipe walls). Activation of metallic impurities in the Flibe from a $NaBF_4$ secondary coolant leak from corrosion products, from target materials, or from a MoF_6 corrosion inhibitor (if used) could result in high dose rates. The occupational risk goal can be met if personnel do not work in the primary coolant loop area. The routine effluent goal is met provided the tritium removal systems in the primary and intermediate coolant loops are made large enough. After 30 y of operation with a 50-cm-thick Flibe jet curtain, the dose rate from the blast chamber (made of high nickel steel such as Hastelloy or stainless steel) would be too high for shallow land burial.

Economic Analysis and Systems Issues

The Safire economics and systems analysis code was used to study some trends in HYLIFE-II (Bieri, 1991). Some but not all of the algorithms in Safire were changed to model the chamber and IHX using Flibe instead of lithium, therefore the trends are only suggestive. A series of curves plotted against repetition rate show the important features (Fig. 9). As the repetition rate drops, the yield per shot goes up dramatically to maintain power. To get a higher yield, the driver energy must go up, which adds dramatically to the total plant cost, especially as repetition rate drops. The electrical power to the driver is practically independent of repetition rate above a few Hertz for our base case gain curve. The driver power is about 100 MWe. As the repetition rate increases the pumping power increases, but not enough to compensate for the falling driver cost, thus the cost of electricity is a falling function of repetition rate. The repetition rate of 1.5 Hz of HYLIFE-I has a cost 60% higher than at 8 Hz.

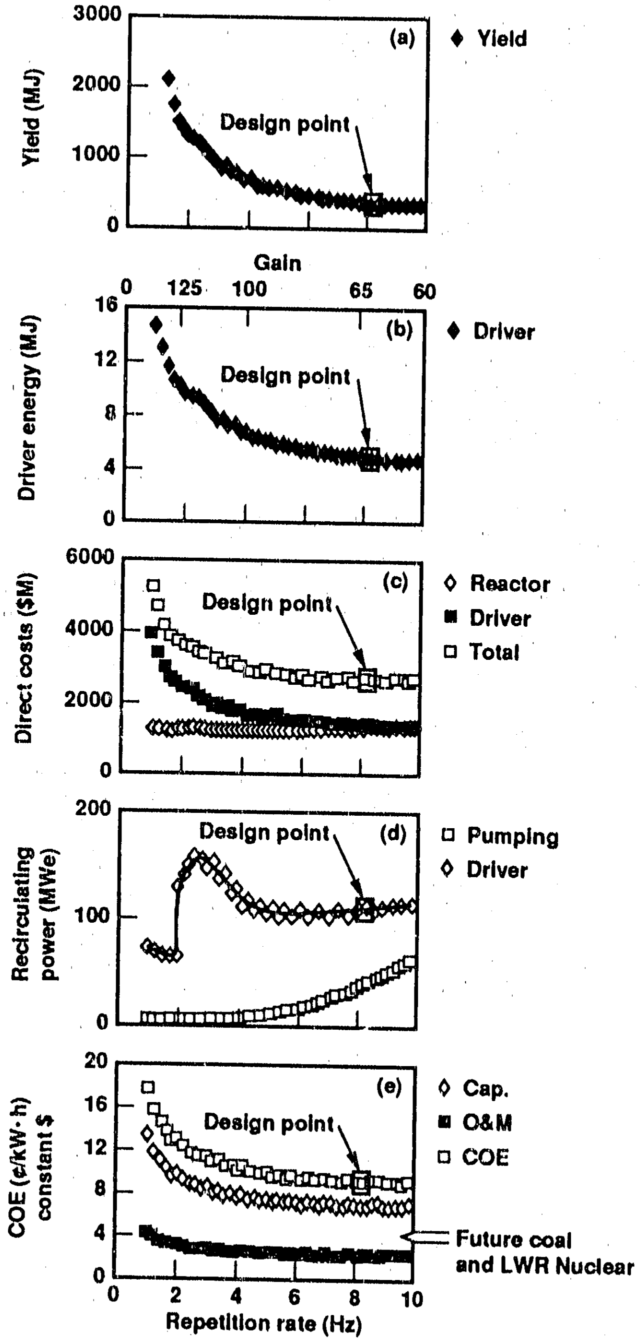

Fig. 9. (a) Yield vs repetition rate. (b) Driver energy vs repetition rate. The gain is given as well. (c) Direct capital cost vs repetition rate. (d) Recirculating power vs repetition rate. The driver power differs from that of the rest of the paper by a factor of 2 because the injection efficiency used in Fig. 1 was 20% and about 35% was used in Safire. (e) Cost of electricity vs repetition rate. Note that this cost is close for the design point of the 9.6 ¢/kWe·h in the paper by Hoffman, 1991.

The cost breakdown is given in Table 3 for a case with a 5-MJ driver operating at a 7.5 Hz repetition rate. This code result is somewhat different from the 8.1 Hz of the rest of the study. The cost of electricity is about 0.27 $/kW·h for current dollars or 0.09 $/kW·h for noninflated 1988 dollars. If the driver direct cost were to drop by a factor of 4, from $1300 M to $325 M, the cost of electricity would drop by 40% (to 0.055 $/kW·h), which is close to that of future coal and light-water reactor (LWR) nuclear power costs of 0.04 to 0.05 $/kW·h.

Summary and Conclusions

In the design known as HYLIFE-II, we have substituted Flibe for lithium and modified the HYLIFE-I design to obtain repetition rates up to 8 Hz. We examined pulsed and oscillating flow concepts to obtain this high repetition rate and to remove splash liquid from the beam lines before the next shot. Condensation is predicted to reduce the Flibe vapor to low enough values to permit an 8-Hz repetition rate. The fire hazard has been eliminated and safety requirements met (but not shallow burial upon decommissioning).

At present, the design and performance of the system depend on many assumptions that must be verified by future analysis and experiment before we can have a high level of confidence in the predicted performance. Some of the key issues include verifying splash removal techniques, tritium removal effectiveness and permeation rates, condensation phenomena and sticking coefficients, heavy-ion accelerator technology and cost reduction, and beam propagation. To be competitive with future coal and LWR nuclear power, the cost of electricity needs to be reduced by a factor of 2.

Acknowledgements

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Table 3. Plant Cost Breakdown

Account	Item		Cost (million $)
20	Land and land rights		5.0
21	Structures and improvements		280.2
22	Reactor plant equipment		551.4
	Tracking, align systems	30.4	
	First wall systems	1.6	
	Tritium extraction systems	4.6	
	Blanket and shield	32.5	
	Heat transport system	80.4	
			149.5
23	Turbine plant equipment		229.8
24	Electric plant equipment		90.9
25	Miscellaneous plant equipment		59.5
26	Main heat rejection equipment		41.1
27	**Drive equipment**		**1397.3**
28	Target factory equipment		128.8
	Total direct cost		**2783.9**
91	Construction services		556.8
92	Home office engineering and services		417.6
93	Field office engineering and services		278.4
94	Owner's cost		194.9
95	Project contingency		423.2
	Total overnight cost		4654.7
		Current $ 1996	Constant $ 1988
96	Escalation during construction	1502.2	0.0
97	Interest during construction	1955.1	434.8
	Total capital cost	8112.0	5089.5
	Cost of electricity (¢/kW h)		
	Capital	21.12	6.79
	Fuel	0.03	0.01
	O&M	6.97	2.24
	Total	28.11	**9.04**

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