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ASSESSMENT OF THE SLOWLY-IMPLODING LINER (LINUS) FUSION REACTOR CONCEPT*

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ABSTRACT

Prospects for the slowly-imploding liner (LINUS) fusion reactor concept are reviewed. The concept envisages the nondestructive, repetitive and reversible implosion of a liquid-metal cylindrical annulus (liner) onto field-reversed DT plasmoids. Adiabatic heating of the plasmoid to ignition at ultra-high magnetic fields results in a compact, high power density fusion reactor with unique solutions to several technological problems and potentially favorable economics.

I. INTRODUCTION

The slowly-imploding liner (LINUS) fusion reactor concept is one of several alternative approaches to magnetic fusion presently under active consideration.[1,2] The primary proponent of this approach and center of experimental activity is the US Naval Research Laboratory (NRL). Additional modeling of the concept in the context of a commercial power reactor has been carried out at a number of US institutions.[3-7] In addition, a study of a similar device has been made in the USSR.[8] The present LASL study[6] involved the development of a comprehensive computer model of the liner implosion dynamics and the plasmoid response. This model is used to assess the LINUS reactor energy balance and determine potentially attractive design points, which were subsequently examined by a preliminary economics model for the determination of direct capital costs and the cost of electricity. In addition, certain LINUS nucleonics and mechanical design issues were addressed. While all of the abovementioned studies have invoked various design options, which will be identified and discussed below, the fundamental approach is common to all and is summarized here.

Imploding-liner magnetic flux compression is a well-known technique for achieving ultra-high (> 50 T) magnetic field strengths for various applications.[9] At thermonuclear temperatures (10-20 keV) these high field strengths allow the confinement of high-density (> $10^{23}/m^3$) DT plasma for times (~ 1 ms) that are determined by the inertial confinement provided by the liner at peak compression (turnaround) and which satisfy the Lawson criterion. Electromagnetic systems exploiting this approach using small, thin, solid metallic liners with fast implosion speeds ($v \sim 10^4$ m/s) have been considered.[2,10,11,12] The vigorous thermonuclear energy release (> 3 GJ in ~ 1 μs) that characterizes these fast implosions is expected to result in the destruction of the liner apparatus and nearby current leads. The economics of refabrication of the destroyed apparatus necessitates high-gain (i.e., Q > 12, where Q equals thermonuclear energy released relative to the liner kinetic energy) systems with potentially severe technological constraints in the areas of pulsed energy transfer and storage, plasma preparation, blast confinement and the economics of material utilization.

In contrast to the fast-liner approach, the LINUS reactor envisages a slower, reversible implosion ($v \sim 10^2$ m/s) of a larger (initial thickness ~ 0.4 m and length ~ 10 m) liquid-metal liner using mechanical or gas-dynamic drive. A field-reversed plasmoid[13] (Compact Toroid) would provide the basic plasma configuration on which the liner would act, thereby eliminating well-known particle/energy end-losses associated with open field line systems.[14] The power cycle can be made reversible if the fusion-product alpha-particle energy gained by an expanding DT plasmoid in each pulse can be matched to the viscous and frictional losses incurred, and the initial driver energy is thereby fully restored. This reversibility allows economical reactor operation for low Q-values (~ 1.2) with nondestructive pulsed energy releases (~ 3 GJ in ~ 1 ms). In addition to providing the plasma heating mechanism, the liquid-metal (Li or LiPb) liner material itself would simultaneously serve the functions of: renewable "first-wall", capable of accommodating severe pulsed thermal loadings (> 50 MW/m^2); tritium breeding blanket; neutron and gamma-ray shield of the permanent reactor structural components; and primary heat-transfer medium. This combination of functions, when coupled with the high power-density performance of the high-beta plasmoid, leads to a relatively compact and potentially attractive scheme for fusion power.

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The basic LINUS reactor operating cycle is illustrated in Fig. 1. In the initial state (a), the cylindrical liner is at rest (radially), and a high-pressure (~ 15 MPa) helium gas reservoir (~ 500 m^3) provides the energy storage required to drive the liner implosion. The liquid-metal liner (T_0 ~ 550 K) is rotated (100–300 rpm) in order to provide centrifugally a central burn chamber and to stabilize the free inner surface of the liner against Rayleigh-Taylor hydrodynamic instabilities at turnaround. The outer liner surface is at all times constrained by the implosion mechanism. As the plasmoid is either created *in situ* or translated into the device from one end of the liner (Sec. III.A.), fast-acting helium isolation valves are opened, and the liner is imploded radially in ~ 20 ms. Radial compression ratios are ~ 10, the liquid-metal liner acts as a non-ideal flux conserver and "dynamic coil" during the implosion. The adiabatic compression of the DT plasmoid and associated magnetic field results in an ignited thermonuclear burn for a short (~ 1 ms) inertial dwell time at peak liner compression (c). During the burn thermonuclear neutrons are deposited in the liner material, which because of cylindrical convergence is ~ 1-m thick at peak compression. Provided that the radial dimensions are appropriately chosen, the alpha-particle energy (pressure) added to the plasmoid can be sufficient to compensate for the mechanical, resistive and viscous losses incurred during the liner implosion and re-expansion; the configuration is thereby returned to its initial state (d). The helium reservoir is repressurized by the alpha-particle driven liner expansion for use on the subsequent cycle. The expansion quenches the thermonuclear burn, and the spent plasmoid is flushed from the system. Recondensation of vaporized liner material on a cooler inner surface and the preparation of another plasmoid completes the LINUS burn cycle. These requirements suggest a minimum cycle time between implosions of ~ 1 s.

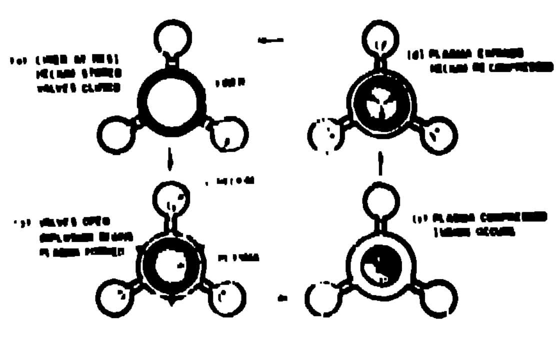

Fig. 1. Schematic representation of the LINUS reactor reversible operating cycle.

The liquid-metal liner is circulated continuously out of the reactor, through the primary coolant loop for heat removal and tritium separation and back to the reactor. A surge tank between the LINUS reactor and the steam generator would minimize adverse pressure cycling. The liquid-metal inventory in the reactor cycles completely in approximately five to ten implosion/expansion cycles. With a time-averaged gross thermal power of 3000 MWt and Li flow of 5000 kg/s the average temperature increase is 160 K between inlet and outlet manifolds. A LiPb system might be expected to require larger heat exchangers and higher pumping power than a Li system. Balance of plant (BOP) features of a LINUS power plant would be similar to most other fusion plants using a liquid-metal primary coolant. Plant output can be expected to be in the range 500–1000 MWe(net). The basics of the LINUS power cycle will be elaborated in subsequent sections.

II. REACTOR PHYSICS MODEL

The LINUS reactor design point is determined by dynamically coupled models describing both the liner and the plasmoid response. Inertial, flux penetration and evaporative heat-transfer phenomena couple the liner/plasmoid models to describe the overall reactor performance.

A. Liner Dynamics

Modeling of the liner dynamics for LINUS usually assumes[5,6,7] that the liner material is inviscid and incompressible. Temperature-dependent liner thermal conductivity, heat capacity and electrical resistivity are used. In the present model[6] mass continuity, momentum and energy conservation equations for the liner are solved subject to the time-varying helium driving-pressure boundary condition at the outer liner surface and the time varying plasmoid pressure at the inner surface. The rotating liner conserves angular momentum as it implodes. Nonlinear magnetic flux penetration into the liner can be included directly[5,6,15] or by means of skin-depth approximations.[9] Flux diffuses ~ 0.1 m into the inner liner surface during the liner implosion. Dissipation of flux in the liner adds to the irreversible mechanical losses and must also be overcome by the alpha-particle energy. Computer simulation of compressible liner dynamics using a full hydrodynamic theory has been performed[14]; these more detailed computations are used to calibrate the faster-running incompressible codes, the former level of computation generally being too expensive for reactor survey calculations. Generally, compressibility effects are monitored using *ad hoc* but reasonably accurate representations.[5,6,17] Compressibility effects will require additional energy investment to achieve a desired compression ratio, but the need to supply this added energy each cycle may be offset by an enhanced liner dwell at maximum compression, the increased burn time leads to an increased thermonuclear yield and higher Q-value.

Energy stored in the compression of liner material, however, is released in the form of shocks which travel through the liner material and act on the permanent reactor structure, which must be suitably strengthened.

An experimental study of slow-liner implosions dynamics without plasma is underway at NRL.[3,18] Stable, and reversible liner compression/expansion cycles have been demonstrated for liner implosions onto magnetic-field payloads. Liner rotation, required to suppress Rayleigh-Taylor instabilities of the inner liner surface at turnaround, is achieved by rotating the entire implosion mechanism or can be achieved by means of tangential injection of the liner material.[19] Either of these techniques may extrapolate to the LINUS reactor.

A typical liner trajectory during the implosion cycle is illustrated in Fig. 2. The scaling of the initial liner radius (~ 2 m), thickness (mass), rotational speed and compression ratio predict sufficient compression to achieve a self-sustaining cycle and to satisfy the nucleonics constraint of ~ 1-m liner thickness at peak compression (Sec. III.C.). The plasmoid separatrix radius is at all times close to the inner surface of the liner as required by the plasmoid equilibrium model (Sec. II.B.).

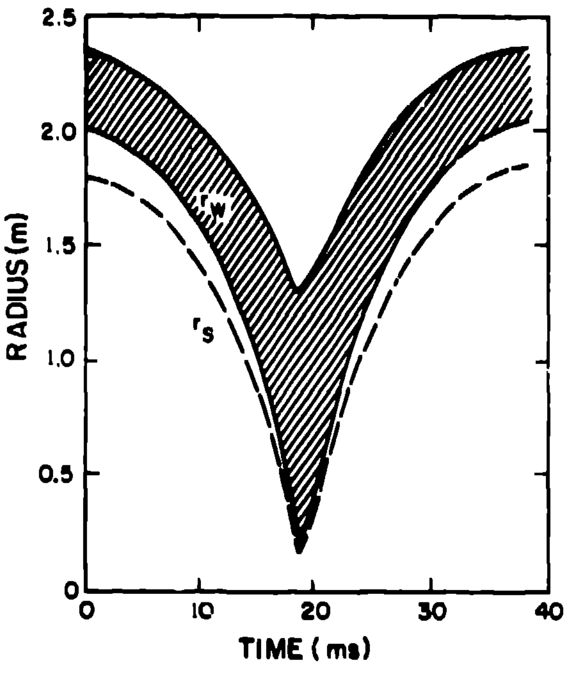

Fig. 2. Typical cylindrical liner implosion trajectory. Inner and outer liner boundaries and the plasmoid separatrix radius are shown as a function of time.

Two distinct options are currently under investigation as liner-drive mechanisms: oppositely-directed axial pistons and a collapsing shell with mass approximately ten times the Li-liner mass. Choice of the appropriate drive mechanism is linked strongly to the choice of liner material (Li or LiPb), plasma preparation technique (Sec. III.A.) and mechanical design issues (Sec III.B.). The present model[6] focuses on the second option.

B. Plasma Model

The DT plasmoid that appears most compatible with the LINUS reactor configuration is the Field-Reversed Configuration (FRC), which is the component of the Compact Toroid (CT) family[13,20] that supports no toroidal field. This plasmoid geometry is illustrated in Fig. 3. Closed magnetic lines inside the magnetic separatrix provide thermal isolation and reduce transport losses. The availability of high-beta plasmoid equilibria for the FRC proposed for LINUS allows high power-density burns that are consistent with the high heat-flux capabilities of the LINUS "first-wall". The presence of an open field line buffer between the separatrix and the liner inner surface can isolate the plasmoid from contact with contaminating liner material evaporated during the burn, thereby acting effectively as a divertor. Flux diffusion into the liner reduces the thickness of the buffer layer and sets a limit on the initial plasma filling fraction.

The CT equilibrium implies[20] that the average plasmoid beta-value $\langle\beta\rangle_s$ within the separatrix radius r_s is given by

$$\langle\beta\rangle_s = 1 - \frac{1}{2}(r_s/r_w)^2 \quad \geq 0.5 \qquad (1)$$

The corresponding beta evaluated within the inner liner surface, $\langle\beta\rangle_w$, is ≤ 0.5, but varies slowly during the implosion. An alternative plasmoid equilibrium may allow higher overall values of $\langle\beta\rangle_w$ if axial pressure is supported by endwalls, and the separatrix radius r_s equals the inner

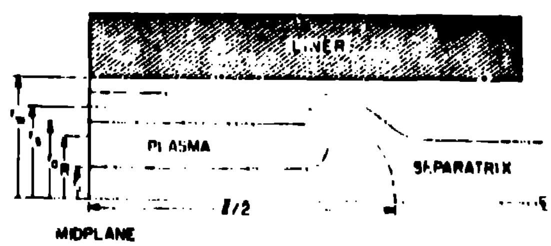

Fig. 3. Compact Toroid (CT) plasma equilibrium configuration as used in LINUS.

liner radius r_w. During compression of this configuration, $\langle\beta\rangle_w$ drops sharply. This behavior may dictate the choice between one of two possible plasma preparation methods (Sec. III.A.). The plasmoid can be produced in situ using hollow, rotating relativistic electron beam techniques[21] or can be formed externally by a Field-Reversed Theta Pinch (FRΘP)[20] that subsequently is translated into the burn chamber through an open end.

Studies of adiabatic compression of these FRC plasmoids and transport properties predict favorable results in the reactor regime.[5,22,23] Accordingly, the present reactor model[6] specifies that both particle and energy confinement times are long compared to the implosion time. The present model uses a three-particle (ion, electron and alpha-particle) point representation of the plasmoid equilibrium.[20] In the limit of ideal adiabatic compression, the plasmoid separatrix and length vary self-consistently under compression of the CT plasmoid according to[20]

$$\ell/\ell_o \sim (r_s/r_{so})^{2/5} \quad , \qquad (2)$$

such that the plasmoid contracts axially to about one half of its original length under full radial compression. The equilibrium model assumes that the plasmoid is prolate (elongation $\ell/r_s > 5$), which for a minimum radius determined by the cycle reversibility requirement (Sec. II.C.) leads to fusion yields of ~ 3 GJ/pulse and time-averaged gross thermal power outputs of ~ 3000 MWt for ~ 1 Hz operation.

The partition of alpha-particle energy between ions and electrons during incomplete thermalization is modeled using a time-dependent, point Fokker-Planck technique.[24] Bremsstrahlung and cyclotron radiation provide a surface heat flux at the inner liner surface, and the neutrons provide a volumetric liner internal heat source (Sec. III.C.), which in addition to the dissipation of magnetic flux in the liner can heat the inner liner surface to its boiling point (~ 1600 K) and evaporate ~ 0.1 kg of liner material. This evaporated material must be recondensed/evacuated between pulses.

C. Design-Point Determination

Scaling of LINUS reactor performance has been considered with a view toward optimizing design parameters and minimizing the reactor size required to achieve self-sustaining cycles.[5,25,26] An estimate for the minimum reactor size (i.e., minimum radius to give a reversible cycle) is given by[5]

$$r_{wo} \approx \langle\beta_f^2\rangle_w^{-2/3} \, P^{-1/2} \, \eta^{1/3} \, (\rho\ell n\alpha)^{-1/6} , \qquad (3)$$

where $\langle\beta_f^2\rangle_w$ is the rms spatially-averaged value of beta at peak compression, P is the drive pressure, η is the electrical resistivity of the liner material, ρ is the mass density of the liner material and α is the radial compression ratio. For drive pressures P ~ 15 MPa, Eq. (3) suggests r_{wo} should be ~ 2-4 m for both the Li-liner/collapsing-shell and LiPb-liner/axial-piston systems depending upon the reversibility of the implosion.[5] The dominant term in this scaling is the requirement for a high-beta payload ($\langle\beta_f\rangle \sim 0.4$) at peak compression. This scaling guides the selection of initial conditions for the simulation codes used to identify specific LINUS operating points.

Parametric and optimization studies are used to identify attractive LINUS reactor design points. These numerical studies generally confirm the scaling of Eq. (3). With the caveat that different simulation models were used by the different institutions involved, Table I summarizes a range of typical LINUS design points reported to date. These design points scope the range of potential LINUS reactor operation and are not necessarily optimized or directly comparable. The present model has been used to confirm the NRL design point summarized in column 4 of Table I and to project the LASL design point in column 5. Tradeoff and optimization studies are reported elsewhere.[6]

III. REACTOR TECHNOLOGY ASSESSMENT

A. Plasma Formation

Two methods have been proposed for preparing the initial LINUS plasma: relativistic electron beam techniques[21] and the Field-Reversed Theta Pinch (FRΘP).[20] The choice of a particular approach will be dictated by the success of its development, and by the interface with the LINUS mechanical design.

In the first approach a DT fill gas is puffed into the burn chamber. A hollow, rotating electron beam is pulsed through an annular slit in one endwall of the device. Interaction of the beam with the gas produces in situ the desired field configuration and plasma heating to ~ 0.5 keV. The endwall is equipped with a shutter mechanism to isolate the electron-beam generator from the reactor chamber during the implosion. In addition a higher-beta plasmoid with a portion of the axial pressure supported by the endwalls can be accommodated. The electron-beam generator energy would be on the order of 40 MJ per pulse (~ 1 Hz) with an efficiency ~ 50% to create a plasmoid with an energy of 20 MJ.

The FRΘP approach produces the plasmoid externally to the liner and subsequently translates it into the burn chamber through an open end. The plasmoid size requirement ($r_s \sim 2$ m, $\ell \sim 10$ m) are similar to those envisaged for the Compact Toroid Reactor (CTOR)[28], but, since the LINUS compression ratio is higher, the initial plasmoid temperature (~ 0.5 keV) and energy can be lower. The parameters of the initial LINUS plasmoid seem attainable by either

TABLE I
SUMMARY OF LINUS REACTOR DESIGN POINTS

	USSR	MSNW	NRL	NRL	LASL
Reference	8	5	2	27	6
Liner material	LiPb	LiPb	LiPb	Li	Li
Driver scheme[a]	AC		AP	RCS	NCS
Plasma preparation method[b]	FROP		FROP	REB	FROP
Radial compression ratio		10	10	10	12
Drive pressure (10^6 N/m^2)		13.8	20.7	13.8	13.8
Initial plasmoid conditions:					
• radius (m)	1.8	1.6	1.9	1.4	1.4
• length (m)	3.0	10.0	7.8	10.0	10.0
• temperature (keV)	0.40	0.63	0.38	0.47	0.42
• density (10^{20}/m^3)		9.3		8.2	8.2
• average beta, ⟨β⟩		0.8		0.75	0.75
• magnetic field (T)		0.69	0.34	0.56	0.56
• energy (MJ)	15	40	13	20	20
Compressed plasmoid conditions:					
• radius (m)			0.08	0.11	0.11
• length (m)		10.0	3.1	10.0	10.0
• temperature (keV)			15	15	20
• density (10^{20}/m^3)			2400	2800	1900
• average beta, ⟨β⟩		0.47	0.55	0.47	0.60
• magnetic field (T)			54	59	60
Cycle time (s)	5.0	1.0	1.0	0.64	0.5
Neutron current (MW/m^2)			305		259
Thermal power (MWt)	1600	3200	1790	170	3350
Net power (MWe)	700	870	507	861	910
Plasma power density (MWt/m^3)			4000		6500
System power density (MWt/m^3)			4.1[c]		4.1
Recirculating power fraction	0.06	0.19	0.15	0.14	.22
Net plant efficiency	0.47	0.27	0.28	0.28	0.27
Direct cost ($/kWe)					1000
Cost of electricity (mills/kWeh)					60

[a] Axial piston (AP), Rotating Collapsing Shell (RCS), Nonrotating Collapsing Shell (NCS), or Axial current (AC). [b] Rotating electron beam (REB) or Field-Reversed Theta Pinch (FROP). [c] Calculated using a volume including the helium gas reservoirs. If only the initial liner volume is included this number rises to ~ 26.

preparation method but considerable developmental work would be required in either case.

B. Mechanical Design

Final selection of a reference LINUS reactor mechanical design rests on the resolution and interaction of a number of physics and technology questions. The requirement for a massive liner, as predicted by Eq. (3), can be met either with a LiPb liner or with a Li liner constrained by a massive collapsing shell driver. Rotation of the liner material can be achieved by rotating the implosion mechanism or by tangential fluid injection into a nonrotating mechanism. Figure 4 illustrates a concept[illegible] for combining the features of the massive collapsing shell with ports for tangential injection of Li. As the azimuthal segments of the collapsing shell move radially inward, they move together to decrease the circumference of the shell[1] and displace the rotating liquid-metal liner inward. Alternate segments are equipped with ports for inlet of new liner material and outlet to the manifolding of the primary loop hot leg. The segments would have to be equipped with sliding seals to isolate the helium pressure reservoir from the liquid Li. Plasma preparation considerations may dictate either a burn chamber with open ends or one with endwalls to support higher values of average beta. Radial dimensions depend on reaching reversible cycle performance as given by Eq. (3) or predicted by more exact numerical simulations.[6] The length of the reactor is in part dictated by the elongation implicit in the plasmoid equilibrium and probably constrains reactor thermal output to be greater than ~ 300 MWt. Generic problems include the chemical compatibility of the liquid metal with the reactor structural material, cyclic fatigue of the liner drive mechanism, achieving vacuum levels in the presence of a free liquid metal surface at elevated temperature and isolation of the plasma source apparatus from the liquid metal and from fusion neutrons. Specific design issues have been addressed elsewhere.[6,27,29,32] These include sliding liquid-metal seals, mechanical design of the implosion mechanism, hydrodynamic shocks ("water hammer"), maintenance

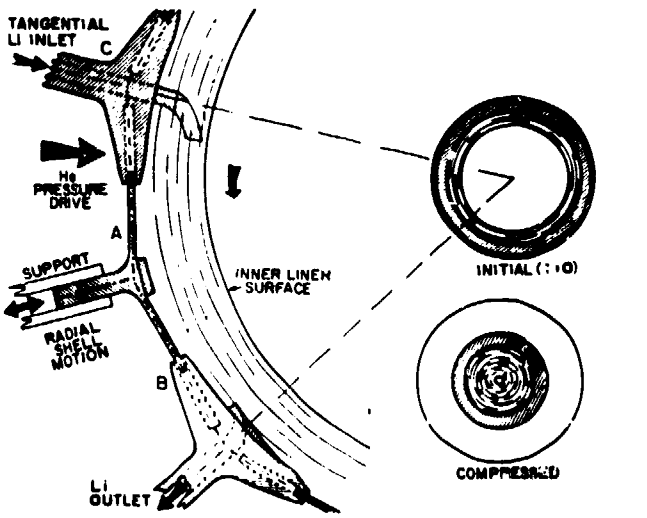

Fig. 4. Conceptual collapsing-shell liner-drive mechanism with tangential injection ports.

considerations and the interface of the LINUS nuclear island with the BOP.

C. Nucleonics

Nucleonics performance of the LINUS reactor includes: the ability to achieve a tritium breeding ratio greater than unity, energy deposition as a function of radius in the liner material, and radial and axial leakage of fusion neutrons from the liner into the structural components of the reactor. Factors influencing the nucleonics performance include: isotopic composition of the liner material, thickness of the liner at maximum compression radius, and thermonuclear neutron source strength. These issues have been addressed using discrete-ordinates transport codes[30] and Monte Carlo techniques.[6,31] Results from the latter scoping calculation are summarized in Fig. 5 as a function of liner thickness at maximum compression. For natural lithium metal and a maximum liner thicknesses in excess of 0.8 m, the tritium breeding ratio easily exceeds 1.4, due to the absence of structural material in the liner. For systems of ~ 10-m length the dominant neutron loss channel is radial rather than axial streaming into the reactor end walls. Radial losses can be reduced substantially for peak liner thicknesses above 1.3 m. The blanket energy enhancement relative to 14.06 MeV/neutron saturates at ~ 1.1 for Li thicknesses near 1.0 m. LiPb liners have comparable leakage and energy enhancement properties and higher tritium breeding ratios ($\lesssim$ 1.9) because of (n, 2n) reactions with the Pb.[30] The volumetric heat source provided by the neutrons and gamma rays decreases exponentially from the inner liner surface with a characteristic distance ~ 0.15 m.

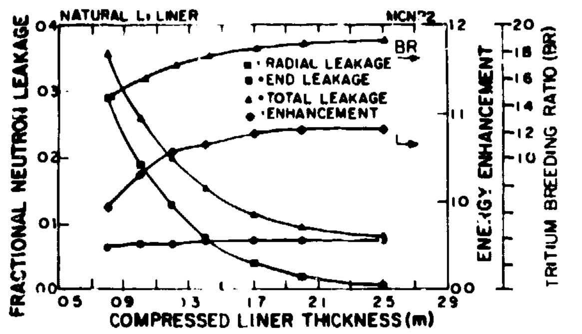

Fig. 5. Summary of typical LINUS reactor nucleonics computations using the MCNP code.

Neutron heating dominates gamma-ray heating by an order of magnitude. Energy deposition near the inner liner surface increases the liner temperature and electrical resistivity, thus enhancing magnetic flux diffusion.[6] Energy deposition times are comparable to the liner dwell time at maximum compression (~ 1 μs) and terminate well before the liner has reexpanded and thinned, indicating that the reactor structure should be adequately shielded for the critical period at peak compression. Axial neutron streaming to an unprotected endwall or to the plasma preparation device, however, could pose a problem. A surge of liquid metal has been proposed[6] as a means of protecting the endwall for systems in which the plasmoid contracts axially.

D. Economics

Several factors combine to suggest that the LINUS reactor will be economically competitive with other fusion approaches. The renewable liquid-metal "first-wall" allows higher wall loadings and higher engineering power densities than are possible with solid structural walls. This characteristic translates into lower material and space requirements for a fixed level of power output; hence, lower costs result. Also, the combination of several functions into the liner itself (e.g., confinement mechanism, plasma heater and primary heat-transfer medium), each requiring separate systems in other fusion systems, should lead to economies that are unique to the LINUS approach. The compact nuclear island may allow shorter construction times than the nominal 10 years assumed here.

Preliminary cost estimates for the LINUS reactor have been made.[6,32] Construction time and BOP costs are determined by scaling laws which are independent of the use of a LINUS nuclear island. Table II summarizes the result of one such estimate for the LASL design point of Table I. It is emphasized that absolute cost values are intended only for the intercomparison of interim LINUS reactor designs and are not intended for absolute comparisons with existing

TABLE II

TYPICAL LINUS FUSION REACTOR ECONOMIC SUMMARY

ACCOUNT TITLE	MILLION DOLLARS	
Land and land rights		2.5
Structures and site facilities		90.0
Reactor plant equipment		460.0
Plasma preparation	12.0	
Reactor mechanism	15.0	
Reactor structure and support	13.0	
Reactor vacuum system	10.0	
Power supply and switching	67.0	
Main heat transport system	212.0	
Auxiliary cooling system	2.0	
Radwaste treatment and disposal	3.0	
Fuel handling and storage	2.0	
Other reactor plant equipment	13.0	
Instrumentation and control	16.0	
Spare parts allowance	16.0	
Contingency allowance	92.0	
Turbine plant equipment		180.0
Electric plant equipment		140.0
Miscellaneous plant equipment		18.0
Special materials		30.0
Total reactor direct capital cost		918.0
Construction facilities, equipment and services (15%)		138.0
Engineering and construction management services (15%)		138.0
Other costs (5%)		46.0
Interest: 10-year construction (64.4%)		798.0
Escalation: 10-year construction (33.8%)		419.0
Total reactor capital cost		2455.0

Assumed plant availability factor	0.85
Direct investment cost ($/kWe)	982.0
Total investment cost ($/kWe)	2627.0
Capital return: 15% (mills/kWeh)	53.0
Operating: 2% (mills/kWeh)	6.0
Cost of electricity (mills/kWeh)	59.0

energy technologies on the basis of present costs.[33]

IV. SUMMARY AND CONCLUSIONS

The LINUS fusion reactor concept results in a compact, high-power density device with unique solutions to several technological problems and potentially favorable economics. Furthermore, LINUS is an attractive option for utilizing the Compact Toroid plasma configuration. Simultaneously, several physics and engineering issues have yet to be fully explored; issues which impact directly on LINUS reactor configuration, size and performance and, therefore, on its attractiveness as an approach to commercial fusion power. Specifically, these issues include: the choice of liner drive mechanism and liner material (Li or LiPb), the choice and performance of plasma preparation technique, the ability to achieve reversible compression/expansion cycles in the presence of nonlinear flux diffusion into the liner material, the ability to recondense and evacuate evaporated liner material and the spent plasmoid in the time interval (~ 1 s) between pulses, and the detailed design/compatibility of the liner-drive mechanism with the liquid-metal liner.

V. ACKNOWLEDGMENTS

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