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HIFSA
Heavy-Ion Fusion Systems Assessment Project

Volume I:
Executive Summary

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CONTENTS

VOLUME I
EXECUTIVE SUMMARY

VOLUME II
TECHNICAL ANALYSES

1. HIF TARGETS

2. INDUCTION LINACS

3. CAVITY TRANSPORT

4. FINAL FOCUS AND BEAM TRANSPORT

5. REACTOR AND BOP SYSTEMS

6. SYSTEMS INTEGRATION AND PARAMETRIC STUDIES

HIFSA

HEAVY-ION FUSION SYSTEMS ASSESSMENT PROJECT

Volume I: Executive Summary

by

D. J. Dudziak, W. B. Herrmannsfeldt, and W. W. Saylor

ABSTRACT

The Heavy-Ion Fusion Systems Assessment (*HIFSA*) was conducted with the specific objective of evaluating the prospects of using induction-linac heavy-ion accelerators to generate economical electrical power from Inertial Confinement Fusion (ICF). Cost/performance models of the major fusion power plant systems were used to identify promising areas in parameter space. Resulting cost-of-electricity projections for a plant size of 1 GWe are comparable to those from other fusion system studies, some of which were for much larger power plants. These favorable projections maintain over an unusually large domain of parameter space but depend especially on making large cost savings for the accelerator by using higher charge-to-mass ratio ions than assumed previously. The feasibility of realizing such savings has been shown by (1) experiments demonstrating transport stability better than anticipated for space-charge-dominated beams, and (2) theoretical predictions that the final transport and pulse compression in reactor-chamber environments will be sufficiently resistant to streaming instabilities to allow successful propagation of neutralized beams to the target. Results of the *HIFSA* study already have had a significant impact on the heavy-ion induction accelerator R&D program, especially in selection of the charge-state objectives. Also, the study should enhance the credibility of induction linacs as ICF drivers.

Objectives

The Heavy-Ion Fusion Systems Assessment (*HIFSA*) study was organized to deal with a specific premise and had as its charge a specific set of objectives. The premise is in the form of a negative statement frequently made concerning commercialization of fusion. The assertion is that fusion in general, and the Heavy-Ion Fusion (HIF) approach to Inertial Confinement Fusion (ICF) in particular, appears to be so costly and requires scaling to such large power outputs that it would not be attractive to the electric utility industry.

Below is the most concise statement of the objectives of the *HIFSA* study, which is intended to find a solution to this programmatic dilemma (and refute the stated premise). It was drafted by the three U.S. Department of Energy (DOE) offices that funded the study.

> Briefly stated, the objective of the study is to perform an assessment of heavy-ion inertial fusion systems based on induction accelerators, including representative reactor systems, beam focussing and final transport, target design, and system integration. Emphasis will be given to systems for electric power production and to design innovations and parameter ranges which offer credible promise of reducing system size and cost. No attempt will be made to review heavy-ion fusion as a whole, nor current programs, except by inference and in summaries of previous studies. Rather, effort will be concentrated on system and subsystem conceptual design and analysis, including cost/performance models for studying and exhibiting major system parameter variations. Identification of needed R&D will be included. It is expected that the study will be used to guide the direction of future heavy-ion fusion programs in the U.S., as well as fill a major gap in current fusion program studies.

Note especially the last requirement, "(to) fill a major gap in current fusion program studies." Over the last several years there have been two comprehensive HIF design studies, HIBALL(1) and HIBLIC.(2) In contrast to the rf-accelerator technology featured in both of these studies, the U.S. program(3) has for several years concentrated on the single-pass induction-linac approach. It seemed incumbent upon the U.S. program to present a study that would fairly examine the systems aspects of the induction linac as a driver for HIF.

Background

In recent years, various critics have expressed opinions similar to Lidsky's (4), that "...even if fusion is found to be technically feasible, at the costs and with the complexities indicated by current estimates, no one needs it." The standard arguments in favor of HIF have always included the economic advantages of high-efficiency drivers, the technical simplifications resulting from the separation of driver and reactor, the advantages of the extensive experience with charged-particle accelerators, etc. However, the cost of the accelerator system, added to the cost of the reactor, balance of plant (BOP), etc., previously always resulted in a total cost that requires a very large power production capacity in order to achieve adequate economy of scale. For example, the HIBALL plant was designed to include four reactor chambers and had a total capacity of nearly 4 GWe. Even at this size, the cost per kWh of produced electricity was about the same as projected by other studies for fusion plants(5-8) at about 1 GWe.

As will be discussed in detail below, a key conclusion of the present *HIFSA* study is that HIF does not require scaling to inordinately large power plants. In fact, plants as small as 500 MWe have reasonable costs; also, staged construction of power plants starting at about 500 MWe appears to be a viable option.

It is likely that the large system studied for HIBALL was, in fact, a result of assumptions in the point design and not just a derived conclusion of the study. In a conceptual study for a point design, the initial design criteria can predetermine the results. An objective of the *HIFSA* study was to find design parameter values for economical smaller sized power plants. This was achieved by examining a broad range of parameter values to determine the cost implications of new technical innovations that would permit extending the currently recognized parameter space. The logic here is that unless one can demonstrate the possible advantage of such an extension, it is hard to get anyone interested in studying the technological problems that it causes.

Another example of the effects of choosing the initial design criteria can be found in a somewhat earlier study(9), which was limited in its scope by funding constraints. Here the potential advantage of a high repetition rate was shown by the results, which tended toward lower power costs at the 10-Hz upper bound that the project adopted for pulse repetition rate for the particular technology that was selected. Because it was clear that power costs more for a lower repetition-rate system, one would like to see the result for a higher repetition rate. However, both the accelerator system (an rf accelerator with storage ring current multiplication) and the reactor system (a 10- to 20-m-radius dry-wall chamber) were designed for the 10-Hz limit. Resources did not permit re-examining the limitations.

In contrast to the various point designs, there was one very important systems assessment(10) led by K. A. Brueckner for the Electric Power Research Institute (EPRI). In this report, Brueckner et al. examined the anticipated cost of electricity for a range of parameters for different drivers. The conclusion, based on the limited technical information available in 1979, was that ion-beam drivers are promising candidates for commercial fusion power plants. A much more detailed assessment is now possible using the new data available from target, reactor, and accelerator studies.

In light of the present economic situation of the electric utility industry, with nuclear plants being cancelled and virtually all previous projections for future power needs being too high, there is understandably no enthusiasm (among those with short-range interests) for large-scale fusion scenarios. Even though any long-range energy forecast will conclude that eventually the world must stop burning vast amounts of fossil fuel and turn to a more environmentally benign and virtually inexhaustible energy resource, the place of fusion as the preferred power source of the future is certainly not enhanced by high-cost fusion scenarios. However, if fission breeders continue to be politically unacceptable in the U.S., fusion in some form is the only alternative available to meet anticipated future demand. (Solar can contribute a limited amount.)

Thus, it is incumbent upon proponents of HIF to document the purported advantages of their technology. To make a significant impact, it is necessary to depart from conventional approaches to HIF. For example, to reduce the capital cost of a projected plant -- at present one of the stumbling blocks to acceptability -- the total power rating has to be smaller, and thus the cost of the accelerator must be reduced. Of course, the technical credibility of the plant must be maintained at the same time, and the cost of electricity (COE) must remain at an acceptable level.

Systems Issues

There is a very large parameter space available to an HIF power plant systems designer. The usual way of considering a commercial ICF system is to divide it into four parts: the driver, the targets, the reactor, and the BOP. Also, there are at least two major items that interface with these four parts: the final beam transport system and the target factory.

The BOP, of course, provides the interface between the reactor and the utility customer. The principal plant performance parameter of interest from the reactor/BOP is the thermal-to-electrical energy conversion efficiency. An important secondary role of the heat exchangers in the BOP is to provide a barrier to prevent diffusion of tritium into the environment. With the exception of the magnetically protected dry-wall concept discussed below, no attempt was made in this study to employ direct conversion techniques such as MHD. The thermal conversion efficiency is principally affected by the temperature of the neutron-absorbing material in the reactor blanket and by the type of heat transport system employed. Thus, even further improvements in HIF plant performance could be achieved with more advanced energy conversion systems (which is also true for some other fusion and conventional concepts).

Another system technology with major impact on the total plant capital and operating costs is the target manufacturing facility. As part of the *HIFSA* study, a major review and update of projected target manufacturing processes and associated costs was performed(11). Typical heavy-ion target cost estimates fall in the range $0.25 to $0.45 (U.S.) per target, contributing significantly to the total COE in higher repetition-rate regimes.

There have been several ICF reactor concepts studied and reported in varying detail over the last several years. The approach in this study was to choose representative reactor concepts from those available; in particular, those with which the participants in the study were most familiar (usually, the concept they had invented). The risk of significantly biasing the study in this way was offset by the presence of reactor designers from two centers, Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL). The reactors included in the study(12) were a "wetted-wall" type in which a thin film of liquid lithium is kept against the wall of a spherical chamber by centrifugal force; a "dry-wall" chamber that uses a magnetic field to protect the wall from ions and to expel target debris, introduced primarily as a generic concept with a high repetition rate (it being recognized that the magnetic field scheme might interfere with beam transport); a "granular-wall" type in which a spinning drum holds lithium-based ceramic granules against the outer wall by centrifugal force (an optimistic case assuming nuclear-grade equipment will not be required); and a "liquid-lithium-wall" reactor. The liquid-lithium-wall reactor, which employs a thick curtain of lithium jets, was introduced into the study as an example of a low-repetition-rate concept that would require a minimum of 0.5 seconds for clearing the chamber between shots. The dry-wall concept could operate up to about 20 Hz, whereas the remaining two concepts could conceivably operate in the range up to 5-10 Hz.

The issue of reactor repetition rate is important because of its significance as a systems parameter that directly determines many other parameters. For example, a 1-GWe (net) power plant might reasonably need approximately 3 GW of fusion power, equivalent to 1.5 GJ/shot at 2 Hz or 600 MJ/shot at 5 Hz. Obviously, these would be very different plants in many respects. Repetition rate can be used to illustrate some of the complexities of a systems study. Among the advantages usually cited for heavy-ion induction linacs is the intrinsic ability to operate at a wide range of pulse repetition rates. The repetition rate for a practical HIF power plant, however, is thought to be limited by reactor cavity clearing time[13]. As will be discussed shortly, economic limitations caused primarily by target costs may force an even more restrictive upper bound on repetition rates.

A simple illustration is as follows: Suppose one builds a 1-GWe HIF power plant designed for 5 Hz. If, after tests, it turns out that all reactor components will operate as well at 6 Hz, then superficially it might appear that the plant could produce 20% more power for nearly the same capital cost, and the cost of electricity would be almost 20% less. From a total systems standpoint, however, it is no longer a 1-GWe plant that was designed. Because the specification for BOP equipment was for 1 GWe, if the system is to operate at 6 Hz, the per shot yield must be reduced or the BOP redesigned for 1.2 GWe. The alternative of reducing the yield implies lower driver energy and lower target gain, because the gain curve is assumed to be a monotonically increasing function of driver energy. The result is that the product ηG is reduced (where η is driver efficiency and G is overall fusion gain). However, the lower energy driver costs less assuming, as we have, that the driver is a heavy-ion accelerator easily capable of the higher repetition rate. Without knowing the specified dependence on repetition rate of both the gain function and the target costs, it is not possible to say whether the increased repetition rate will increase or decrease the overall COE. It is possible, however, to say that there can be an optimum repetition rate, above or below which the COE is higher.

The encouraging result from the *HIFSA* study, which we will examine in the next section, is that the nearly optimum repetition rates for COE lie in a somewhat broad range between 3 and 7 Hz, where feasible reactor concepts exist. An interesting sidelight is the issue of driver cost for higher repetition rates. Some concern has been expressed about higher cost for a higher repetition rate heavy-ion accelerator. As was demonstrated in the preceding example, the higher repetition rate accelerator will cost less for fixed electric power because it is, in fact, a lower energy machine.

It was recognized quite some time ago that the key to reduced cost for HIF was to reduce the cost of the accelerator. Prior to the *HIFSA* study, a computer code known as LIACEP was written at the Lawrence Berkeley Laboratory (LBL) to find optimum design parameters for the multiple-beam induction linacs being studied. In an earlier paper by Faltens et al. presented at the Palaiseau Conference[14], a number of options for reducing the cost of the linac were examined. Several of these, such as increasing space-charge-limited current by decreasing the allowed minimum betatron tune, were based on the hope that future experiments would confirm the feasibility of the idea. The lower minimum tune is, in fact, one of the important experimental advances achieved by the HIF program. In addition to cost savings resulting from different choices of physics parameters and accelerator achitectures, cost reductions based on engineering design, materials selection, and manufacturing techniques are now being studied(15) by LANL in conjunction with an industrial contractor, the BDM Corporation.

Study Organization and Participants

This *HIFSA* study began in 1984 and was carried out over a period of about two years, with participation by several institutions, each contributing in its particular areas of expertise. The multi-institutional approach had an additional advantage of providing the different perspectives of national laboratories, universities, and industry; the interaction and mutual critique provided a final product that was more than just the sum of many individual expert contributions. Whereas the project leadership was provided by LANL, a Steering Committee (chaired by W. B. Herrmannsfeldt of the Stanford Linear Accelerator Center (SLAC) and including representatives from DOE, EPRI, and national laboratories) provided general policy guidance and review of the project as it developed.

An important aspect of the approach taken in the project management was the involvement of an industrial contractor with extensive experience in conceptual design, costing, and tradeoff studies for fusion power plants (magnetic as well as inertial confinement). This invaluable experience and consistent approach was brought to the study by McDonnell Douglas Astronautics Company (MDAC), which has participated in most of the major fusion reactor studies cited abvove. Previous experience by MDAC also facilitated the development of a global HIF systems tradeoff and costing computer code -- the ICCOMO code discussed in detail in Volume II of this report.

Listed below are the principal participants, along with a partial list of their roles and responsibilities.

Los Alamos National Laboratory (LANL)	-- Overall project management and coordination -- Overall systems integration, parametric studies, and evaluation -- Target physics

	-- Beam-plasma interaction -- Target fabrication, handling, and costing -- Charge and current neutralization -- Beam transport/stability in reactor cavity -- Reactor cavity concepts
Lawrence Berkeley Laboratory (LBL)	-- Induction linac system -- Final beam transport and focus
Lawrence Livermore National Laboratory (LLNL)	-- Target physics -- Reactor cavity concepts -- Plant concepts and economics
McDonnell Douglas Astronautics Company (MDAC)	-- Reactor systems and BOP -- Overall systems integration, parametric studies, and evaluation -- Systems code development -- Cost scaling
University of Wisconsin	-- Cavity clearing
Sandia National Laboratory	-- Beam transport/neutralization in reactor cavity

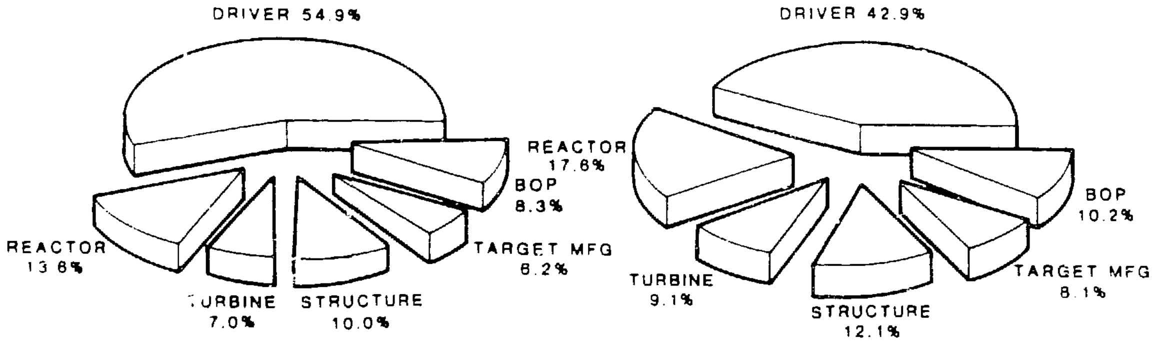
Study Results

Two important computational tools (16,17) were developed for the *HIFSA* study and are discussed in detail in Volume II of this report :

1. The LBL linac optimization computer code LIACEP was extensively updated(16)
2. The computer code ICCOMO was developed by MDAC, permitting examination of large areas of commercial plant parameter space (17) in order to find local optima

Probably the most important technical results of the study came from re-examining the cost-saving ideas that were in the Palaiseau paper by Faltens et al.(14) The paper by Hovingh, et al.(16) shows how some of these ideas, modified by newer experimental results, make it possible to envision significant cost reductions, especially by using higher charge-to-mass ratios. Most of the study was done for q = +3, A = 130, although the results would be scarcely affected if A = 200 were used. Figure 1 illustrates the decreased fraction of the cost attributable to the driver, as well as the decrease in COE, by going to q = +3. All costs quoted for the *HIFSA* study are based on the standard DOE Nuclear Energy Cost Data Base (NECDB)(18), using 1985 dollars. These costs were then benchmarked against those using methods developed for several magnetic-fusion studies(6-8) and were not significantly at variance.

The methods and results from the systems study are extensively reviewed in papers presented at the May 1986 International Symposium on Heavy-Ion Fusion as well as in Volume II of this report . In particular, detailed discussions of many aspects of the systems costing, tradeoffs, and sensitivities can be found in Refs. 12 and 17. Readers are referred to these papers and report contributions for the assumptions and methods that were employed. Here we would like to single out some of the most significant results.



+1 IONS (75.2 MILLS/kWh)

+3 IONS (59.9 MILLS/kWh)

Fig. 1: Comparison of direct capital cost breakdowns for drivers with charge states +1 and +3; for a reference case consisting of a single wetted-wall cavity, a single-shell target, two-sided irradiation, and a net plant output of 1GWe. All estimated COE values are computed using the NECDB(18), in 1985 dollars (U.S.).

Figure 2 displays the results from the study for the wetted-wall reactor concept. The data plotted are COE vs repetition rate for five different types of targets. The target types (described in more detail in Ref. 17) are (1) one requiring planar-symmetric illumination; (2) a double shell; (3) a single shell; (4) a range-multiplied concept; and (5) a hypothetical advanced single-shell concept with gain multiplied by 2.5, which might represent a target with polarized fuel, for example. A number of key issues are illustrated by this plot:

1. High repetition rates are not always better. This conclusion results because the ηG product suffers at high repetition rate, as was discussed earlier. The direct cause is that the cost of providing for targets, and eventually also the cost of recirculating power, begins to dominate the COE. On the other hand, 3 Hz is much better than 1 Hz because of the lower driver energy requirements.

2. Symmetrically illuminated targets, which may use the beam energy more efficiently, still result in higher COE. The greatly increased cost of the final beam transport system is the determining cost factor.

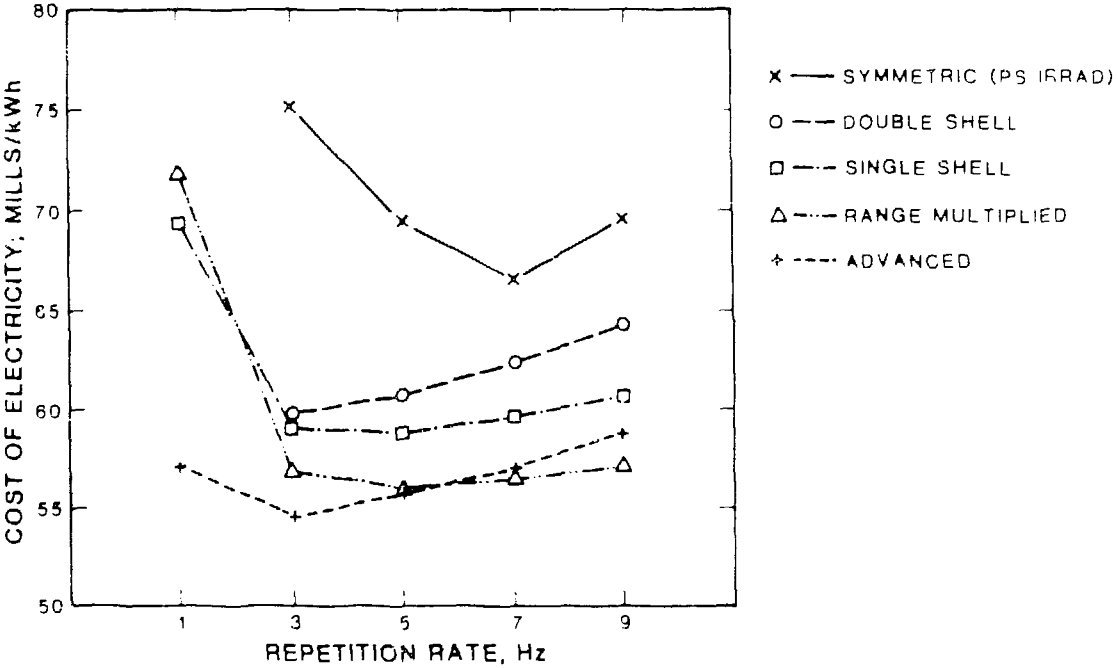


Fig. 2: Results for the wetted-wall reactor concept. Variation of the estimated COE values with repetition rate, for the five different target concepts. Values are for the reference case of a 1-GWe plant with a single wetted-wall cavity, +3 ions of mass 130, and gamma values of 0.03 for two-sided irradiation with 16 beams total (0.225 for the planar-symmetrically irradiated target). NECDB costing(18) in 1985 dollars (U.S.) was employed.

3. Very high-gain targets are not extremely important. The range-multiplied and advanced targets provide somewhat lower COE, but not by much (note the depressed scale in Fig. 2), and even then only if they don't cost more or need better beam quality. The benefit is small (~5%) because the standard single-shell target still should have an adequate ηG product. Because "Advanced Concept" is a euphemism for "assuming some untested concepts to improve target performance," it is important to note that such hopes, while potentially useful, are not necessary for competitive COE from HIF.

In Figs. 3 and 4, we display two sets of bar charts showing the "near optimum parameter ranges" for different target concepts and reactor designs. Each bar covers the lowest 5% of COE for that combination. Note that this is for q = +3, so the accelerator voltage is reduced by a factor of three compared to an accelerator for q = +1. The accelerators are thus much shorter than had been assumed previously, and hence the driver cost is reduced by almost a factor of two (as reflected in Fig. 1). The lowest COE is obtained for the granular-wall (with optimistic assumptions concerning non-nuclear grade construction) and wetted-wall reactors. Both of these are near optimum in the broad ranges 3-9 Hz and 6-13 GeV.

Next, in Fig. 5 we display the comparison of cavity types using single-shell targets with 16 beams in a two-sided illumination scheme. Note that plants employing the wetted-wall and the more optimistic granular-wall reactors are very close in minimum COE (to the point where the differences are most likely within the uncertainties of the modeling process). Even for the other two reactor types, the minimum COE is not excessive, indicating that the regions of parameter space opened up by the widely differing technical operating conditions of the various reactors are all economically accessible. Perhaps here the real message is absolute COE. This study was performed by MDAC under EPRI funding, using technology projection and costing methods they previously applied to magnetic fusion studies. In spite of the requirement for <u>only</u> 1 GWe, the COE is reasonably competitive with other fusion studies and other technologies. Thus, HIF is clearly a fusion concept to be considered for further development.

It was recognized long ago that the HIF drivers can service several reactors. In HIBALL, four reactors were used. Thus, these results from the *HIFSA* study penalize HIF by limiting the requirement to 1 GWe. However, the study also looked at the COE for a 500-MWe plant and found it to be ~60% higher; for a 1.5-GWe

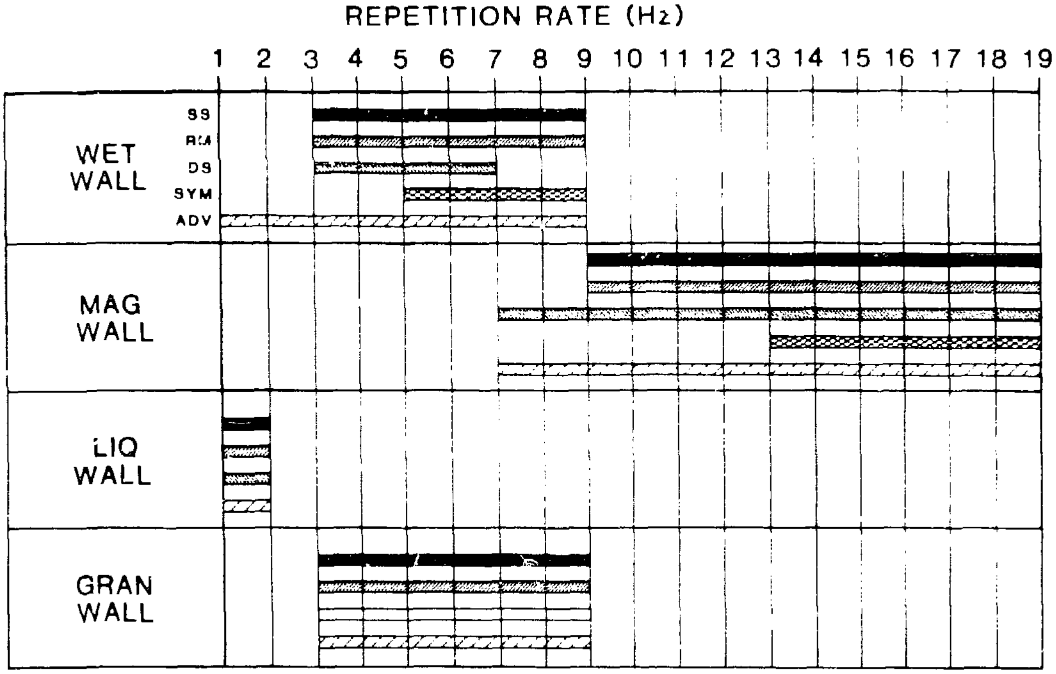


Fig. 3: Near-optimum (within 5%) repetition rates for the four reactor types and five target types. Values are for a single-cavity, 1-GWe plant using +3 ions.

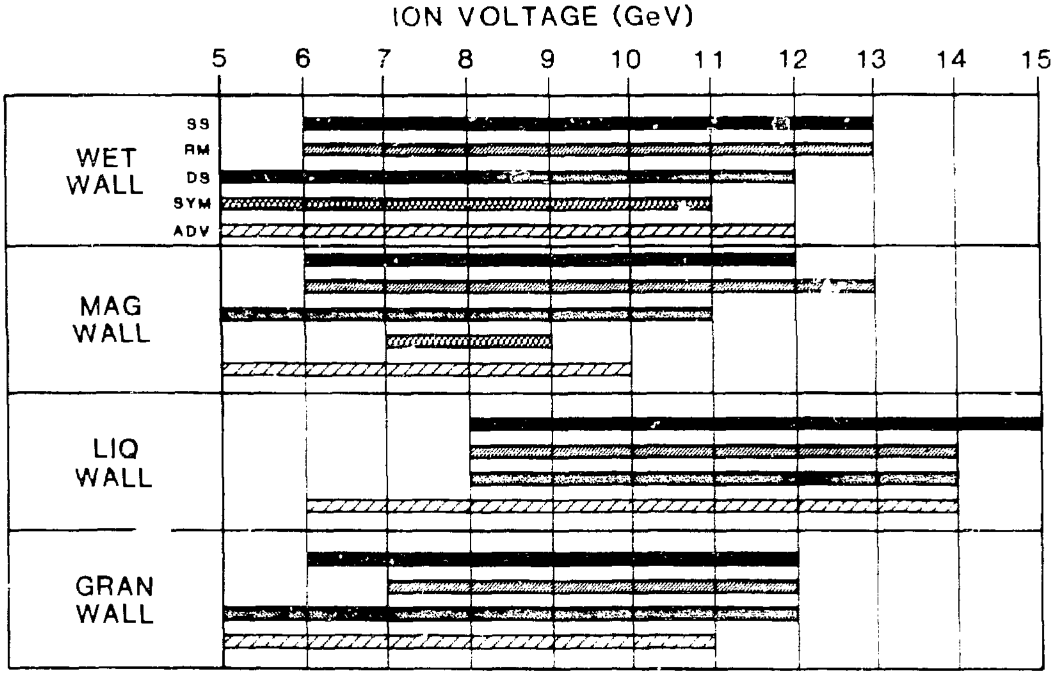


Fig. 4: Near-optimum (within 5%) ion voltages for the four reactor types and five target types. Values are for a single-cavity, 1-GWe plant using +3 ions.

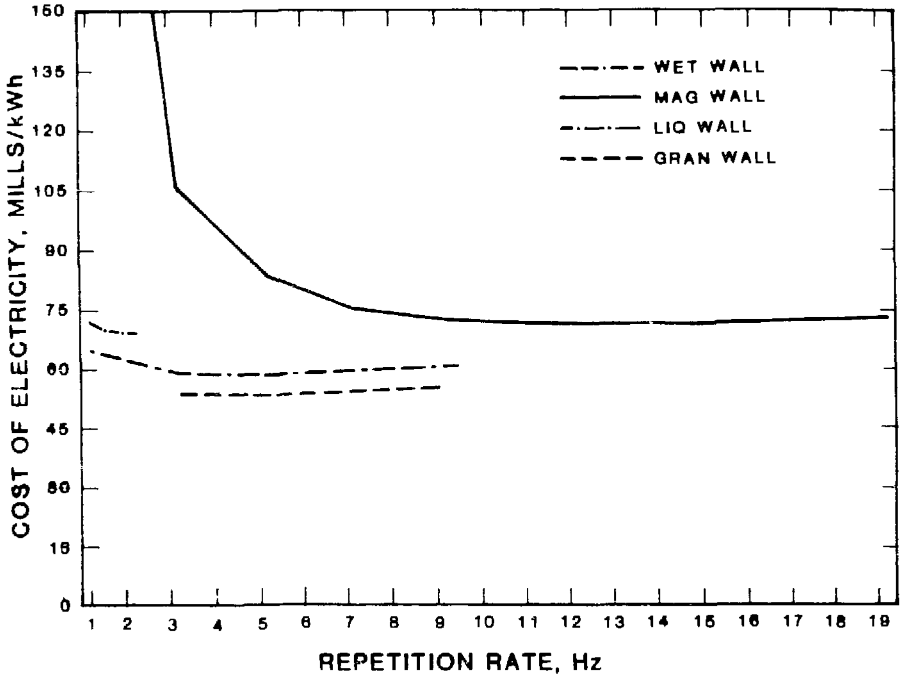


Fig. 5: Range of applicable retetition rates, and associated COE, for the four reactor cavity types. All COE values are for a single-cavity, 1-GWe plant using +3 ions of mass 130 in 16 beams for two-sided irradiation of single-shell targets, with $\gamma = 0.03$.

plant the COE is reduced ~25% relative to the 1-GWe case. These results are illustrated in Fig. 6, where the components of the direct capital cost are also presented for each of the three power levels. One would not expect anything else considering the laws of economy of scale, but it is encouraging to find that even at 500 MWe, the COE is not excessively high.

Conclusions and Recommendations

There were many accomplishments of the *HIFSA* study, among which we mention three in particular.

1. For future optimization of HIF systems, the development of the ICCOMO code and improvements in LIACEP are significant and tangible products of this study.

2. The discovery that optimal repetition rates exist in a broad minimum for COE, in the range 3-9 Hz, can guide future reactor designs.

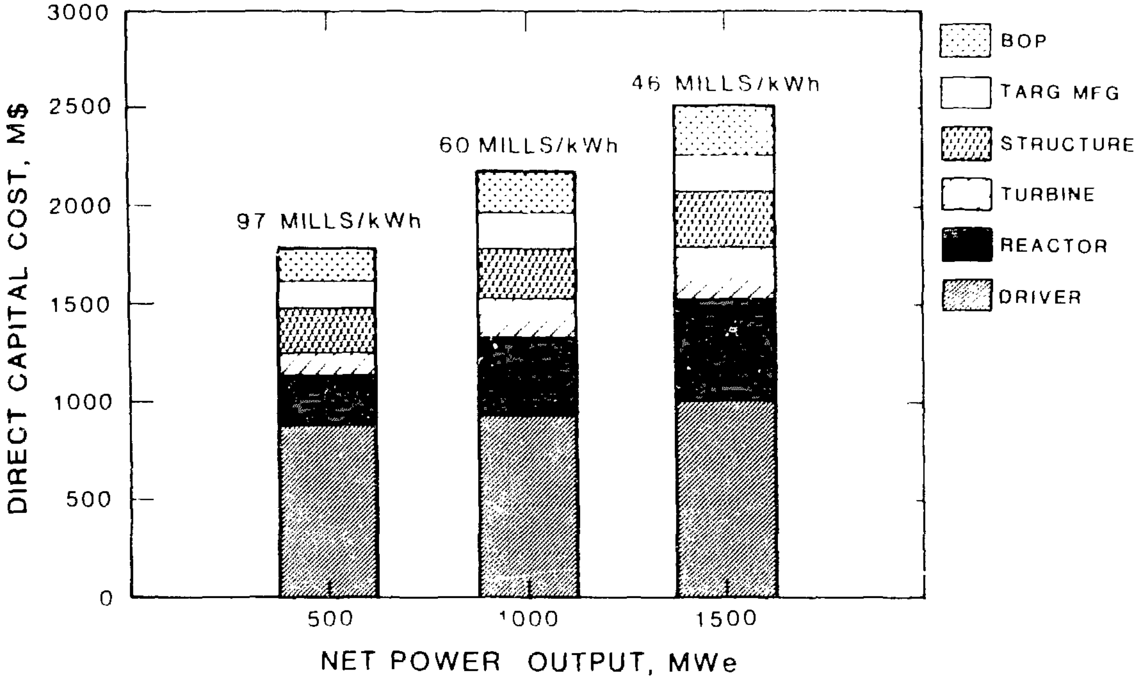


Fig. 6: Cost breakdown for the near-optimum case of a wetted-wall cavity reactor plant at three power levels. All cases are for two-sided irradiation of a single-shell target with 16 beams of +3 ions of mass 130. Costs are in 1985 dollars (U.S.) as computed using the NECDB methods and data(18).

3. The understanding that major reductions in the cost of induction linacs result from using higher charge-to-mass ratios and multiple beams can point to new research and development directions. The potential savings result directly from the experimental progress made in stable beam transport for intense ion beams in the SBTE and MBE-4 facilities at LBL.

It is worthwhile to note that although the study was done mostly for $q = +3$ and $A = 130$ or $A = 200$, very similar plant performance results may be obtained for $q = +1$ and $A = 67$. The reasoning is that, whereas there is good progress with MEVVA sources for multiple-charged heavy ions, it may be that some price must be paid (for example, in higher emittance). With the same electrical current, a beam of $q = +3$, $A = 200$ ions would have the same beam properties as a beam of $q = +1$, $A = 67$ ions, except that the latter would have a slightly longer range. The range difference becomes less noticeable at lower kinetic energies, corresponding to the shorter range favored for better target performance. Thus, the accelerator R&D could continue now without necessarily concentrating on how to make a good ion source for charge state +3.

An additional important conclusion of the study not discussed here yet is that with the higher currents it is certainly necessary to invoke neutralization during final transport. Work by Stroud(19) improves our confidence that streaming instabilities will not destroy the emittance during transport through the target chamber.

One of the principal objectives of the HIFSA study was to help define future directions for the (HIFAR) program.(20) We noted that the significant cost savings identified by the study are based on experimental results in the SBTE and MBE-4 experiments at LBL. Both of these are small-scale experiments. It is most important to move into significant beam power and particle velocity, if for no other reason than just to gain more relevant experience with scaled-up systems. History has taught us to expect new phenomena when key parameters, such as beam power, are extended by orders of magnitude. The LBL group has proposed an accelerator apparatus called ILSE that has scaled-up power and higher particle velocity as its chief goals.

Historically, heavy-ion accelerators were considered to be the ion-beam approach that could use vacuum transport to hit the pellet and avoid all the complexities of beam/plasma interaction physics. The present understanding of reactor chamber physics and the use of higher currents (higher charge state, lower kinetic energy) make this old hope appear as wishful thinking. Beams will neutralize, and neutralization must be invoked just to hit the target. The neutralization phenomena must be studied, and any possible relevant experiments must be planned. Also, the handling of intense beams in bending and focusing systems must be demonstrated. The high intensities needed at the pellet require longitudinal compression of the pulse as it nears the target. The expectation is that longitudinal space charge forces will control the longitudinal momentum spread and permit adequate control of chromatic aberrations. This needs verification both by simulation and experiments. Fortunately, it should be possible to perform relevant experiments at low kinetic energies.

The other areas in which R&D is especially needed have all been known for some time. The advantages of multiple beams in the accelerator, for example, are well known, and MBE-4 has demonstrated that at least four beams can be accelerated together. Techniques for instrumenting a multiple-beam accelerator are needed for orbit diagnostics and corrections.

The largest number of beams is needed in the low velocity part of the linac. Merging of beams after the injector area, if possible, can make the magnetic transport system much more economical. Experiments with merging are planned for the ILSE program.

Significant cost savings can be achieved with advanced engineering and manufacturing techniques, especially for induction cores and pulsers. A study(15) of manufacturing and materials cost reduction is now under way at LANL. Except for the areas noted above (merging and final transport), most of the physics issues for HIF are in hand. Now we need practical experience with engineering and operation-of-high-intensity systems.

Any list of required HIF R&D contains ion source development. Although a good start has been made, much work remains on the 16-beam, 2-MV injector developed at Los Alamos.

In summary, the objectives of the *HIFSA* study were achieved; viz., the assessment of present induction linac, target, reactor, and associated technologies as to their potential for commercial electric power generation, the extension of technology studies in several areas where gaps existed, and the development of a comprehensive systems model for wide-ranging cost/performance tradeoff studies(21). The results of the tradeoff studies indicated newly promising areas of induction-linac operating parameter space, with resulting influence on the accelerator R&D program directions. Perhaps most encouraging was the demonstration that HIF technology is robust, offering a wide variety of system configurations in which COE values are comparable to those for other conceptual fusion power plants at ~1 GWe. Comprehensive presentations of all major aspects of the *HIFSA* project are presented in Volume II of this report.

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