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Report of the FEAC Inertial Fusion Energy Review Panel: July 1996

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This report presents the results and recommendations of the U. S. Department of Energy Fusion Energy Advisory Committee (FEAC) review of its Inertial Fusion Energy (IFE) program. The subpanel charged with the review was chaired by John Sheffield of Oak Ridge National Laboratory. The FEAC, to which the subpanel reported, was chaired by Robert Conn of the University of California at San Diego.

KEY WORDS: Fusion; fusion science; fusion energy; inertial fusion energy.

I. SUMMARY

Charge to Panel

This report provides an analysis by a Fusion Energy Advisory Committee (FEAC) Panel, of future program options for the Inertial Fusion Energy (IFE) component of the Fusion Energy Sciences Program of the Office of Fusion Energy Sciences. The report is in response to the following request to FEAC from the Director of the Office of Energy Research:

"Charge to the Fusion Energy Advisory Committee for an Inertial Fusion Energy Review.

Since 1990, the fusion program has had a mandate to pursue two independent approaches to fusion energy development, magnetic and inertial confinement fusion. In magnetic fusion, our strategy is to continue to use international collaboration, especially participation in the International Thermonuclear Reactor, to pursue fusion energy science and technology. In inertial fusion, our strategy has been to assume the target physics is the highest priority activity and would be developed as a part of the weapons research program; and, indeed, the next step in the development of target physics, namely the National Ignition Facility, is proceeding into construction in Defense programs.

Based on the Fusion Policy Advisory Committee Report of 1990, we had taken as our highest priority in inertial fusion energy the development of heavy ion accelerators as the most desirable driver for energy applications. That development program has met all of its milestones and has received numerous positive reviews, including one by the Fusion Energy Advisory Committee (FEAC), which in 1993 recommended a balanced Inertial Fusion Energy

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program of heavy ion accelerator development, plus other smaller scale efforts, at $17 million per year.

The potential for inertial fusion energy has been judged to be real, but the fusion program no longer has as a goal the operation of a demonstration power plant by 2025. Given that the basic mission of the fusion program has changed from energy development to fusion science, and that funding for the entire fusion program will be constrained for some number of years, I would like FEAC to again consider inertial fusion energy and recommend what the new Fusion Energy Sciences program should be doing in support of this future fusion application, and at what level."

Review Process

The panel was briefed by Dr. N. Anne Davies, Director of the Office of Fusion Energy Sciences (OFES) of the Office of Energy Research, and by Dr. David Crandall, Director of the Office of Inertial Confinement Fusion (ICF) and the National Ignition Facility (NIF) of Defense Programs, on the roles of IFE and ICF in the Department of Energy. A summary was given of previous reviews of the IFE program, including that of the Fusion Policy Advisory Committee (1990) and the FEAC Panel 7 (1993). The panel was asked by Dr. Davies, and agreed to assume, that NIF would be built and that the IFE mission belonged in OFES. Presentations were also heard on the progress and prospects in the various areas of the program from a number of the collaborating institutions. Written comments were received from experts in the field.

It was agreed that, given the short timescale for conducting this review, the panel would rely on the extensive technical background provided in the FEAC Panel 7 report, supplemented by the more recent information given in presentations and written comments.

Overview

Inertial confinement of plasmas provides an important fusion option with the potential for a competitive power plant. There are two inertial fusion program elements. The OFES/OER/DOE has the mandate to support energy applications through its Inertial Fusion Energy (IFE) program. The ICF program in DP/DOE is motivated by science based stockpile stewardship. The DP program is funded in FY 1996 at about $240 M/year, about 30 times the OFES inertial fusion energy program. Obviously, much of the key reseach will be undertaken in the DP program. The IFE program must concentrate on energy issues not covered by DP, and try to position itself to apply the results of DP research in the energy area. Significant developments in the ICF program continue to provide crucial scientific and technical results that support the IFE component. It is important to capitalize on this symbiotic relationship between IFE and ICF. Further, progress in the IFE program since the 1993 FEAC-7 review has been good, despite its being funded at the $8M per year level rather than the then-recommended $17 M level.

A strong IFE program is a proper and important component of the restructured OFES/DOE program. Challenging and relevant scientific issues need to be resolved, especially in the areas of collective effects in high current accelerators and beam-plasma interactions. With the ICF physics development in Defense Programs, and supporting science and technology and the high repetition rate driver development in the OFES program, the United States is positioned to lead the world in developing IFE science and technology.

The following finding, concerning funding for the IFE program, represents a medial opinion of the Panel. A minority of the Panel would support a more aggressive approach and a comparable minority, a less aggressive approach. The medial position of the Panel is that there should be an increase in the non-driver part of the IFE program beyond the present level to strengthen the scientific and technological understanding of the prospects of IFE and to involve a wider range of institutions in these efforts. The medial opinion is that, to achieve this goal, the funding for the IFE program should be increased to about $10M per year for the next few years. Such an annual budget would allow maintaining the pace of heavy ion accelerator development. In total, the program would provide the breadth of support necessary for initiation around the year 2000 of a construction project for an integrated research experiment using a multi-kJ heavy ion driver with a target chamber.

Findings

Progress Since 1993

- An opportunity for wider participation and more rapid scientific progress has been created by a substantial declassification in the ICF area funded by DOE's Defense Programs;
- The progress in the preparation of the National Ignition Facility (NIF), for which the Inertial Confinement Fusion Advisory Committee (ICFAC, November 1995) indicated that "as far as ignition is concerned there is sufficient confidence that the program is ready to proceed to the next step in the NIF project. . . .";

- Excellent progress in:
  - the understanding of target physics through the NOVA program;
  - heavy ion accelerator technology;
  - operation of improved, fusion relevant, laser systems—KrF (Nike at NRL), the new Omega Upgrade Direct Drive Facility (U. Of Rochester) and diode pumped solid state development (at LLNL);
  - operation of light ion systems that support some beam-target interaction assumptions; and
  - improved understanding of power plant issues and refinements that could lead to competitive fusion power plant prospects.

Science and Technology

The inertial fusion program involves much exciting science and technology, as seen in the continuing developments in the target physics area. Although most of the science of target design and implosion is undertaken in the ICF Program, there are opportunities, because of declassification, for a broadening of the work in the IFE Program. The development of energetic, high current density, space-charge-dominated beams and their focussing onto a target involves fundamental science—instabilities, beam-plasma interactions, plasma lenses, etc.—and a great opportunity to compare sophisticated computer models with experiments. These developments will have importance broadly across the accelerator field. The development of the drivers and of power plant systems requires innovative new technologies. Work to date has already led to some significant advances.

The panel finds the work at LBNL to be of high scientific quality and was impressed that the ongoing theory and experiments, even at present funding levels, will contribute significantly to the science base required for heavy ion driver development and beam propagation. The complementary IFE programs at LLNL and other institutions have also made impressive progress.

Challenges

Many scientific and technological challenges remain to be overcome before the goal of an economic power plant can be realized. Success is not assured although we see no show stoppers. In rough order of importance, the most critical of these are:

- Overcoming the hydrodynamic instabilities (and possible laser-plasma or beam plasma instabilities), and obtaining adequate symmetry to produce a high gain target yield. We must rely on NIF for the basic experimental proof or disproof.
- Providing viable protection of the target chamber against the X-rays, neutrons, blast, and debris to be expected from the pellet explosion. This may be particularly critical for the final focusing optics of a laser system. An analogous issue for heavy ions is finding an adequate mode for beam transport, compatible with the chamber environment that is present with various wall protection schemes.
- Development of a driver with adequate efficiency, rep-rate, and reliability.
- Mass producing targets at a cost of about $0.25 apiece, including their injection and accurate positioning in the target chamber.

All of the above must of course be done at a cost compatible with economic electricity production.

Timeframe

The pace and content of the IFE program is driven by a succession of anticipated events in the DP and OFES programs:

- In the Restructured Fusion Energy Sciences Program, it is envisaged that there will be "a growing portfolio of new experiments . . ."
- By 1999, the International Thermonuclear Experimental Reactor Engineering Design Activity will have been completed, the NIF should be well advanced in its construction phase, assuming the presently proposed schedule is met, and the Tokamak Fusion Test Reactor program at PPPL will be completed. This is a period in which some new initiatives—including one in IFE—should be ready for consideration by OFES.
- The proposed NIF program is designed to have the capability to ignite a D-T target in the 2005 timeframe.

Opportunity for the U.S. in IFE

A strong IFE program is a proper and important component of the restructured OFES/DOE program. Challenging and relevant scientific issues need to be resolved, especially in the areas of collective effects in high current accelerators and beam-plasma interactions. With the ICF physics development in Defense Programs and supporting science and technology and the high repetition rate driver development in the OFES program, the United States is positioned to lead the world in developing IFE science and technology.

Logic for Heavy Ion Accelerator Driver

In agreement with previous reviews of inertial fusion energy by the National Academy of Sciences and two FEAC panels, we consider the heavy ion accelerator to be the most promising driver for energy applications. The reasons include the relatively high efficiencies that are possible with accelerators, exceeding 30%, and the demonstrated high reliability of high power accelerators operating at rep rates of several Hz. In contrast, the best laser options—KrF and DPSS—have efficiencies less than 10%. Among the alternatives for heavy ion accelerators, the induction linac (or possibly the recirculating version) is well matched to the multikiloamp currents and submicrosecond pulse lengths required for inertial fusion.

An alternative accelerator approach is the rf/storage ring driver. This approach fits well within the existing European accelerator programs, and is a valuable complementary program. In a presentation at the review meetings, our European panel member agreed that the induction linac has potential cost advantages in comparison with the rf linac/storage ring approach they are exploring.

In the longer term, breakthroughs in the development of laser targets, including direct drive and other approaches (such as the fast ignitor described below) could modify the decision on drivers. Reassessment of the driver and target should be made on a regular basis.

Need for Integrated Research Experiment

Excellent progress has been made in the past by the IFE Program in accelerator development on key issues (e.g., beam bending, merging, pulse compression, final transport) through a series of small scale experiments—closely coupled with theoretical modeling—to understand fundamental aspects of the basic beam phenomenology. These innovative small scale experiments and associated theoretical modeling should continue. However, progress at the level needed to fully evaluate the HIF approach to IFE will also require an integrated experiment capable of resolving the basic beam dynamics issues in the accelerator, studying the final focusing and transport issues in a reactor-relevant beam parameter regime, and evaluating the target heating phenomenology.

With a succession of delays in the funding of the (less ambitious) ILSE project, the IFE team believes a more comprehensive "Integrated Research Experiment" (IRE) should be the focus of the next decade of IFE research and development. The IRE is discussed in more detail in section IID. The overall objective of IRE is to provide the data base needed to support a decision to proceed with the construction of a full scale IFE driver, on a time scale consistent with NIF demonstrations of fusion target performance.

While various options for such a facility have been considered over the years, no particular option has been selected. Consequently, the Panel received only limited information on this topic. Nevertheless, it seems clear that trade studies of various options leading to the development of a conceptual design for the IRE should be a major focus of the heavy ion program over the next two to three years.

Target Physics

The key scientific issue for any IFE system is target physics. This will not be tested conclusively before the experiments on the NIF. Nonetheless, the best possible simulations are indicated for a program of this importance and scientific value. LLNL has just completed the first succesful "integrated" simulation of a heavy ion driven target. We believe it is important for other groups to develop new codes and perform independent confirmatory simulations as one element in a driver decision. We believe that the recent declassification makes this feasible, and that this essential task could be undertaken by an MFE theory group, providing an important link between the MFE and IFE communities with eventual mutual enrichment. Developing new target physics codes is a challenging multiyear project. In the interim, MFE theorists could contribute to such issues as beam propagation, and participate in target design using existing codes.

Program Needs Derived from Power Plant Studies

Several comprehensive, conceptual design and systems studies have been completed. They show the potential for and requirements for IFE to provide competitive power plants. Other than development of the driver, the key issues are:

- Demonstration of high gain at moderate driver energy.
- Development of chamber technology, including wall protection and cavity clearing schemes at power plant repetition rates.
- Development of power plant technologies to provide tritium self-sufficiency, radiation

shielding, radiation resistant materials, and low-cost target production.

The IFE program within OFES must have sufficient breadth, beyond driver development, to cover those other areas that are critical to its feasibility and competitiveness. Progress in these areas will influence driver research priorities and should provide the data needed in the near term to perform meaningful experiments on NIF that are important to IFE.

Priorities Outside Heavy Ion Accelerator Development

The panel suggests the following priorities for the broader program:

First priority:

- Wall protection scheme evaluations and development.
- Confirmatory simulations of heavy ion driver target performance.

Second priority:

- Cavity clearing technologies at IFE repetition rates.
- Development of the final focussing optics for laser systems. (It is assumed that final focussing and transport studies for heavy ion beams are undertaken as a part of the accelerator development program.)

Third priority:

- Target factory studies.
- Work on rep-rated laser systems. This is an important area but until IFE funding increases substantially, development of only the presently most promising driver can be afforded.
- Shielding, blanket and tritium studies.
- Detailed power plant conceptual design studies. The extensive studies made in recent years have identified the principal issues for IFE. It is time now to concentrate the scientific and technological studies on these specific issues.

Roles of DOE/Energy Research and DOE/Defense Programs, and International Collaboration

This Panel has reviewed and commented on the IFE program conducted by the OFES of Energy Research. The program benefits from an essential symbiotic relationship with the ICF program conducted by Defense Programs. The Panel notes that the NIF program expects to offer testing time to a range of institutions and program interests. A 1994 workshop, organized by DP, identified a wide range of IFE relevant issues that could be addressed by NIF. The Panel is not in a position to comment on the balance between the various elements of the DP program, but feels strongly that greater clarification is needed regarding possible implementation of these IFE relevant elements of the DP-supported ICF program.

A joint IFE steering committee between ER and DP, consisting of all interested parties, should review this program on a regular basis.

In addition, such a committee might be used to facilitate international cooperation in IFE. This FESAC/IFE panel did not review the foreign programs, except for a brief discussion of some European developments (see IIC). We note, however, that the French are building a NIF-scale facility, that there is a proposal in Europe to expand IFE, and that there are significant IFE programs in Japan and Russia.

Budgets

The position of the Panel is that there should be an increase in the non-driver part of the IFE program beyond the present level to strengthen the scientific and technological understanding of the prospects of IFE and to involve a wider range of institutions in these efforts. We believe that this is needed even though there is a large measure of breadth because of related DP-funded efforts. For a total OFES/IFE budget in the range of $8M or greater, this total investment in non-driver science and technology should be $2M–$3M per year.

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At the present OFES/IFE budget level of $8M, a significantly increased investment in program breadth is desirable but would be achieved at the expense of a substantial slowing of the pace of development of a heavy ion accelerator. At lower budget levels, the elements of the program would have to be done serially rather than in parallel, delaying the pace of the program beyond that needed to meet the goals above. At some lower level, it would be impossible to mount a coherent driver development program. The FEAC Panel report identified the $5M/year case as one in which "there is no credible program for the development of a heavy ion fusion energy option."

II. BACKGROUND INFORMATION

Target Physics

The gain required for an ion-beam power plant can be estimated from the requirement that the recirculating electrical power should be limited to about 25%, and hence 10% of the output fusion thermal power. For an assumed accelerator efficiency of 35%, gains of about 30 are needed.

Recent LLNL integrated calculations of 2-sided, indirectly driven ion target designs predict a gain of 40–50 with a 6–7 MJ driver capable of focussing to a 6 mm radius spot size. These calculations consider the ion energy conversion to X-rays in the target, and the subsequent radiation transport and pellet implosion. Most of the calculation involves the same physics as that involved in the LLNL NIF laser implosion predictions, which have been verified by LANL simulations. The validity of these codes has been tested against Nova experiments and judged (by ICFAC for example), to provide an adequate basis for proceeding with NIF. We conclude by analogy that an adequate basis of target physics exists for proceeding with consideration of other aspects of an HIF design. A wide variety of possible target designs for HIF requires further study. It is very likely that more optimum designs are feasible. We believe that it would be desirable if independent propagation and target physics codes would be implemented and we recommend that the participation by scientists from one or more MFE groups be encouraged.

There are alternative concepts for IFE reactors. Direct drive targets, while requiring very high uniformity, allow better coupling of driver energy to compressed fuel (by a factor of 2–5) and hence potentially higher gain. Such advantages in gain might allow KrF lasers or DPSSL's to overcome the large efficiency advantages of HIF. Experiments on the Omega facility (University of Rochester) and NIKE facility (NRL) should give some quantitative data on these prospects in the next several years. Direct drive HI targets are in principle feasible, but questions regarding deposition nonuniformity from such sources as beam overlap and multiple-beam interactions have not been adequately evaluated.

Still more drammatic improvements in gain or minimum size may be available with the fast ignitor. Many physics and technology issues remain to be explored, and the first significant data base on this exciting new prospect will become available in the next 2–3 years on Nova.

We conclude that indirect-drive HIF remains the driver option of choice. Enough data should be forthcoming on direct drive and fast ignitor prospects in the next 3–4 years, that it should be possible to better evaluate the prospects of IFE with lasers at that time.

Heavy Ion Accelerator (Progress, Issues and Prospects)

1.) Progress since 1993 on issues identified by FEAC panel 7 (page 7)

The LBNL injector program has demonstrated the production and acceleration of a single driver-scale ion beam, in a linear geometry. The parameters of the beam are 2MeV, 0.25mC/m (790 mA) of K^+, with emittance of 1mm-mr. Beam energy variation ($< \pm 0.15\%$) is also consistent with the full-scale driver requirements. The goal of producing a multi-beam injector was not met because funding was not provided. A schematic diagram of an accelerator experiment, indicating issues and progress, is shown in the figure below.

Matching a high-current beam into an alternating gradient (quadrupole) channel is important. Experiments are beginning with a 6-quadrupole matching section; 3-D computer simulations project succesful operation.

Transverse beam combining is considered advantageous because it allows for electrostatic quadrupole transport of many beams (at low energy) with small apertures. Once combined (at about 100 MeV), subsequent acceleration and transport is carried out with magnetic quadrupoles that have large apertures. Beam combining experiments have begun at LBNL.

Transport of a low-current space charge dominated beam (mAs) through a 7-quadrupole magnetic focussing system has been achieved successfully at LLNL. Construction has started at LBNL of a high current (800 mA) system.

Recirculation is being investigated; potential advantages include reduced total length, saving on total number of induction modules, and allowing smaller individual induction modules. An overall reduction in cost could thus be realized. Many issues must be dealt with here: beam control is likely to be more difficult; emittance growth in a curving beam with space charge effects needs evaluation; the pulsers must be programmed with a different time history for each pass of the beam; energy recovery from dipoles appears necessary; and vacuum requirements are significantly more stringent (∼2 orders of magnitude). A prototype recirculator is being developed at LLNL to address many of these issues experimentally; it is not expected to have a functioning 360 degree ring before FY98.

Final focusing of the beam onto target presents numerous scientific and technical challenges. Preliminary experiments have begun at LBNL; on self-focusing (*plasma lens*), have led to a 20-fold increase in beam intensity; and on laser-induced plasma channel guiding; much more work needs to be done in this area in the future.

In parallel with the experimental investigations, theoretical modeling of beam transport and dynamics has made excellent progress in the last few years. Highlights include: particle in cell simulations of beam merging results; detailed modeling of beam transport through electrostatic quadrupoles, with space-charge effects; simulations of the recirculator approach, which are used to help design the experiments; evaluation of resistive wall mode effects on longitudinal beam stability; numerical studies of chamber focusing and transport, including effects of charge and beam neutralization; investigation of beam-beam interactions for multiple beams converging near the target.

There has been a number of hardware developments. Lower cost ferromagnetic materials have resulted from making better use of industrial products. High repetition rate, reliable, flexible waveform controllers and generators have been developed for beam acceleration. Low-cost pulsed magnetic quadrupoles and a high gradient (100 kV/m) electrostatic quadrupole system has been developed.

The studies described above were carried out primarily to support the design and experimental program of the Induction Linac Systems Experiments (ILSE) accelerator. The advances described above would allow an ILSE-type accelerator to have twice the performance at a similar cost to the original proposal. This experience leads to the expectation that much larger gains in performance will be achieved in the proposed program over the next few years. For these reasons the program is considering an integrated experiment with a 3–30kJ accelerator as the next step.

2.) Issues in the near term program.

- Continued development of ion sources to achieve longer life and lower emittance is needed.
- Development should continue on compact multi-beam, high current injectors.
- A demonstration is required of the injection and multi-pass recirculation of a space charge dominated beam, while maintaining beam quality.
- The maximum transportable current density limits should be determined.
- Validation of beam simulation codes for 100's of lattice periods is required.
- Demonstrations of beam combining are required with validation of codes, and of beam focussing with and without neutralization.
- Development is also required of low cost components and assembly techniques.

3.) Feasibility of Heavy-Ion-Beam-Drive for High-Gain Targets:

It must be demonstrated that high-gain targets can be driven by heavy ion beams. Some modeling has been carried out to investigate this very broad issue, and there is some related information from light ion target designs and simulations. Recent simulations from LLNL, using the modeling developed for NIF, predict adequate gain for ion-beam indirect-drive targets. These simulations are supported by a wide variety of data from the NOVA laser at LLNL. Much of the detailed experimental evaluation of the prospects for ion-driven ignition and gain must await results from NIF. In the meantime, development of indirect drive target designs for NIF, which are ion-beam relevant, should continue.

4.) Additional Science & Technology Questions.

a) *Focusability*: The ability to maintain beam quality (focusability) at high current is the principal scientific challenge for the development of HIB drivers. In addition to the topics and progress noted in section 1 above, some additional physics issues worthy of consideration include:

(i) The goal of developing a capability to do "end-to-end (of the accelerator)" simulation of beam propagation is expected to play a key role in optimizing the MJ driver design. A linear driver will pass the beam through of order a thousand lattice periods. Therefore, experimental validation of code accuracy over long times will be important. Existing particle-in-cell (PIC) methods have shown good agreement in short experiments, and have been used to obtain converged results over hundreds of lattice periods. However, maintaining a sufficiently low noise level for long-time accuracy will be computationally challenging. The much longer beam path in a recirculator driver makes it even harder to model. Intermediate tests of understanding in this key area of long-time transport are expected to come from the small recirculator experiments (of order 300 lattice periods) and possibly more efficient "reduced" description simulation methods. Experimentation should help to determine whether piecing together results from separate analyses of carefuly selected elements/accelerator modules is adequate to accurately describe an entire machine.

(ii) The physics and feasibility of self-pinched propagation in the chamber remains an important and open issue. Experiment/theory tests on this subject would be valuable.

(iii) The filamentation of an HIB driver for ICF is an important issue that could benefit from some reexamination. Earlier studies [E. P. Lee, et al. Phys. Fluids 23, (1980) 2095] considered the growth of filaments in a charge-neutralized ion beam propagating through a resistive plasma medium. They concluded that filamentation required higher pressure than the ~1 mtorr present in current fusion chamber designs. Although these results are reasonable, powerful new computational capabilities can profitably be used to examine higher density regimes of interest.

b.) *Beam-target interaction*: Intense radiation from the target, produced when the target is heated by the early time portions of the beam, can affect propagation of the remainder of the beam. Langdon et al's calculations [A.B. Langdon, Nucl. Instr. and Methods in Physics Res. A 278, p 68, 1989, and also Carlo Rubbia, Nucl. Instr. and Methods in Physics Res. A278, p 253, 1989] indicates that "photoionization of half the beam by the time it propagates to within 20 cm of the target is likely." A later more accurate kinetic calculation following a slice of ion beamlets, as they merged and hit the target, showed a 5% loss of ion deposition within the intended 3 mm radius spot (A.B. Langdon, Particle Accelerators, Vol. 37–38, p 175–180, 1992). This calculation assumed no neutralization due to collisional effects and photoionization of vapor in the chamber. Such neutralization effects further reduce the electric field and the trajectory changes. This issue should be included in the examination of all potential focussing schemes.

A European Perspective. Ingo Hofmann, GSI Darmstadt

At GSI Darmstadt (a major German national laboratory in heavy ion nuclear and applied research) there exists a laboratory commitment to develop heavy ion drivers and beam physics as well as plasma physics experiments (with heavy ions) towards the goal of IFE based on the RF Linac & Storage Ring concept. This is complemented by a basic science program funded by the Federal Ministery of Research on "High Energy Density in Matter" since 1980 (beam plasma experiments, target theory and driver development), which supports primarily University groups, again with GSI in a lead lab role. Both programs add up to approx. 2 Mio. DM/y. [An addendum: as far as the relatively "low-level" funding of HIF in Europe one should keep in mind that, generally, salaries of scientific staff are not included and that the GSI facility is a large investment (300 Mio. DM) which came from other sources].

In other European countries (except Russia) there are smaller groups and individuals in a number of institutions who work on different aspects of HIF. I estimate these efforts as presently $<$0.5 Mio. DM/y. The feasibility study proposal "Ignition Facility" submitted to the European Union would allow establishment of a formal European collaboration within the "keep-in-touch" position towards ICF (in total 1% of the yearly 200 million ECU fusion budget). Although a "Study Group" has been inaugurated in March 1995, the decision on behalf of the EU is still pending. It should be mentioned here that the report of the recent ESTA (European Science and Technology Assembly) working group, established by the previous Commissioner for Energy Research as a consulting body, was in favour of gradually raising the 1% level for ICF to 10% of the total fusion budget. This is to be seen in part as a consequence of the US declassification in energy related ICF.

In Russia there is a collaboration between Arzamas (their former weapons lab) and ITEP/Moscow with the purpose of using the existing proton/heavy ion synchrotron at ITEP for target experiments at the kilojoule level, which requires some hardware extension to implement a foil stripping device. According to unofficial information this project expects funding at the $10 million level (in total).

Technical Prospects RF vs. Induction Approach

The RF approach is based on broad experience with linacs and storage rings, however not under the extreme beam power density conditions required for HIF. In the European Study we are not yet in a position to say how many storage rings and final beam lines are really needed for a reactor driver. The induction approach is highly innovative and appears to have a larger cost saving potential due to its very high current capabilities. Since both schemes are still in a research phase they need to be pursued as complementary approaches. There is a lot of synergism which opens possibilities for effective collaboration in a number of beam physics issues, including final focusing.

Beam Physics–a Science?

In my estimate the LBNL/LINL beam physics group is doing excellent work and has developed capabilities which are unique in their kind. The codes are used under the special technical boundary conditions of injectors and the induction acclerator, where they have developed an extremely high standard of modeling. Applying their 3-D simulation tools to areas of concern in the larger accelerator community (including the RF approach to HIF) would be an excellent opportunity to foster the links with the broader field and give the group the recognition it truly merits. At the same time, confidence in their simulation tools would build up in the accelerator community. I believe that it is largely the detachment from too specialized an accelerator environment (especially at low energy) which is a condition for recognition of beam physics as science.

Integrated Reasearch Experiment

The overall objective of an Integrated Research Experiment (IRE) is: to provide the capability to investigate the science of heavy ion beam/target interactions; and to provide a data base that, together with the results from the broadened base program and NIF, will be sufficient to support a decision to proceed with the construction of a full scale heavy ion IFE driver. The design parameters for this proposed experimental facility are not fixed at this point, although a number of representative examples of facilities at about the right scale have been studied in the past.

The overriding issue in the development of heavy ion accelerators is the transport and beam control of very high power, high brightness ion beams. The generation, axial compression, and merging of multi-beam, high-current, heavy ion beam pulses in the presence of strong electromagnetic interactions with the accelerator structures must be carried out, while maintaining a good beam emittance (brightness). There are no fundamental impediments, but it is clear that a variety of passive and active beam control systems are needed. Experiments at the scale of the IRE are essential to develop the experience and understanding needed before a full scale driver can be designed with confidence. The induction accelerator technology has demonstrated adequate reliability, rep-rate capability, and efficiencies in moderate scale experiments. The main issue in the technology area is achieving these performance capabilities at a low enough cost to meet the economic goals.

The committee concurs with the IFE Program's description of the science and technology elements that should be included in this integrated experiment:

- The IRE should provide the experimental capability for resolving the basic beam dynamics issues involved in the generation, acceleration, and pulse compression of a heavy ion beam, through the accelerator and through the beam transport to the target chamber.
- It should be capable of studying experimentally a wide range of schemes for focusing and transporting the heavy ion beam onto the target, including vacuum ballistic transport, plasma neutralization, plasma channel transport, and self-focused transport.
- It should provide an experimental evaluation of energy deposition and target heating with heavy ion beams in hot ionized matter, in the temperature regime of a 100 eV or more, including any effects that radiation from the target might have on the focusing and steering of the ion beam passing through various background gases in the target chamber.
- The operation of this facility, at a rep rate of several Hz, will also provide engineering data on the efficiency, reliability, and costs at a scale that will allow meaningful extrapolation to a full scale induction linac driver.

To achieve these objectives, the IRE should be designed with the flexibility for experimental studies over as wide a range as practical, both in the operational modes of the beam in the accelerator as well as the beam parameter variations possible for final focusing, transport, and target heating studies. For example, with plasma-based ion sources, a range of ion masses is possible in principle, if the appropriate flexibility is provided in the beam transport system.

The challenge faced by the IFE Program in the design of the IRE is how to achieve these objectives at an affordable cost. The general parameter range under consideration is a pulse energy in the range 3 to 30 kilojoules, at a beam voltage of 100 to 300 MeV (with singly charged K, for example). At a pulse length of order 10ns (after compression, at the target) the beam current is several kiloamps. The beam current in the accelerator should then be several hundred amps, sufficient to reach the "heavy" beam loading regime necessary for high efficiency operation of the accelerator cells. It is also necessary to be in this regime to fully evaluate the longitudinal dynamics of the beam in the presence of significant feedback from beam loading of the accelerator cells. This feedback is especially important in understanding the amplification of current waveform fluctuations (klystron-like bunching modes), and the viability of various correction schemes for maintaining smooth pulse waveforms.

To accurately model the phenomenology of a full scale driver in a machine that is about 10–20 $\times$ smaller, scaling of several of the key parameters is necessary. Major variables that have a significant effect on the cost include the final beam voltage, the pulse length (or the joules in the pulse), and the ion mass. Over the next two years, trade studies to identify the most promising parameter sets for the IRE should have a very high priority.

Previous designs of a so-called "High Temperature Experiment" (HTE), with many of the same objectives, explored a similar parameter regime, see for example, "Accelerator Inertial Fusion—A National Plan for the Development of Heavy-ion Accelerators for Fusion Power," Los Alamos National laboratory Report LA-UR-81-370, Dec. 10, 1981, and "Heavy Ion Accelerator Research Plan for FY84–FY89", Los Alamos national laboratory Report LA-UR-83-1717, May 1983.

Progress on Potential Laser Drivers for IFE

Both KrF and Diode-Pumped Solid-State Lasers (DPSSL's) have potential as drivers for IFE. Although both laser systems have projected laser efficiencies of less than 10% for IFE applications, the projected target gains for Direct Drive targets could be high enough for economical energy production. Although quite speculative, the potential enhanced gain of direct drive targets ignited by a fast ignitor laser beam could further relax the laser efficiency requirements, or reduce the laser energy required for IFE.

Since 1993, significant progress in the ICF Program has been made in developing both the target physics and technology required for Direct Drive IFE with lasers. The NIF is being designed to allow testing of Direct Drive targets. Programs to establish the laser requirements for laser beam smoothing and hydrodynamic instability control are being actively pursued on the recently completed Omega glass laser at the University of Rochester and the KrF Nike laser at the Naval Research Laboratory.

The 60 beam Omega laser is capable of delivering 30–45 KJ of laser light at 0.35 mm in a flexible pulse shape. Omega is the principal U.S. facility for exploring direct drive implosions and will be used for establishing the requirements for direct drive ignition on the NIF.

The 56 beam KrF Nike laser can deliver 2–3 kJ of energy at 0.248 mm to planar targets. Nike will be used primarily for the study of imprinting (target perturbations created by laser intensity variations in the laser beam), and subsequent hydrodynamic instability growth. Individual Nike beams have achieved spatial intensity uniformity of about 1% when averaged over the 4 ns duration of the laser pulse. This a factor of several better than can currently be achieved with glass lasers although improvements planned for Omega are expected to significantly improve its beam quality.

System studies of KrF lasers have concluded that 5–7% efficiency is feasible (perhaps somewhat more if waste heat from the amplifiers is recovered). The Nike laser, which was not designed for efficiency or high repetition rate, operates at about 1.7% efficiency. For IFE, amplifiers would need to be developed which demonstrate the required efficiency, repetition rate and durability.

Flashlamp-pumped Solid-State lasers do not have the efficiency or heat handling capability required for IFE. For example, the NIF, as designed, will operate at about 1/2% efficiency. However, solid state lasers which use a gas-cooled crystal gain medium, pumped with efficient diode lasers have projected efficiencies near 10%. Many elements of such a system have been demonstrated on a small scale at LLNL. A 2 joule DPSSL at LLNL, which used the crystal Yb:S-FAP as the gain medium, has operated at 25 Hz with gas cooling and has demonstrated an ability to handle heat fluxes in excess of those required for IFE. Larger scale DPSSL lasers would take advantage of the technology developed for the NIF. A major issue for DPSSL's is the cost of diodes. For IFE applications, diode costs of \$0.10/watt or less are required. Current diode costs are about \$10/watt and the cost goal for diodes to be used on the NIF is \$1/watt. Diodes have a variety of commercial and military applications and their price is projected to decrease as these markets grow.

A generic issue for laser IFE is protection of the final optics against neutrons, X-rays, and debris from the target and chamber. Grazing incidence metal mirrors (GIMM's) and self-annealing fused silica optics operated at several hundred degrees Centigrade have been proposed as solutions. An OFES sponsored program to further evaluate possible optics protection approaches could help establish criteria for determining laser requirements.

DP is supporting a modest development effort on DPSSL's and a research program on the fast ignitor. At present there is no funding for KrF rep-rated high power amplifier development. Although we are not recommending an OFES program on laser driver development at this time, we do recommend that OFES continue to evaluate

Table 1. Top-Level Issues For Inertial Fusion Energy

1.	Sufficiently High Target Gain at Economical Driver Size: a) G > 30 for indirect drive with ion beams. b) G − 100 for direct drive with lasers.
2.	Driver cost, efficiency, reliability, and lifetime: a) Demonstration of the required performance of a driver operated in a repetitive mode. b) Performance, reliability and lifetime of final optics.
3.	Fusion Chamber: a) Feasibility and performance of a viable wall-protection scheme. b) Cavity clearing at IFE pulse repetition rates. c) Tritium self-sufficiency in a practical IFE system. d) Adequate radiation shielding of all component6s. e) Pulsed radiation damage and thermomechanical response of first wall/blanket, particularly for concepts without thick liquid protection.
4.	Sufficiently low cost, high volume, target production system.

progress on laser drivers and direct drive targets in DOE Defense Programs. We also recommend that OFES act to encourage international collaborations with the U.S. on laser driver developments directed toward IFE.

IFE Power Plants (Progress and Needs)

A number of excellent, comprehensive, conceptual design and system studies for IFE power plants have been completed over the last few years. Innovative concepts have been developed through these studies, and they have contributed to providing a greater understanding of the prospects and issues for IFE. These studies have shown the promise of IFE as a competitive energy option. The key technical issues, derived from this work, are listed in Table 1.

The target physics and performance, and target-beam interactions will be addressed primarily by the DP program, partly in the R&D for NIF, and then through experiments on NIF.

Several issues affect the viability of fusion chamber designs for IFE. The first issue concerns the feasibility and performance of a viable wall-protection scheme. A practical IFE system requires protection of the solid chamber wall from rapid degradation due to the extremely high instantaneous heat and particle loads associated with the X-rays and debris from the target explosion. While researchers agree on the need to protect the solid chamber wall, there is no consensus on the best means to achieve this. The two leading schemes proposed for wall protection are: 1) thick liquid layer, and 2) thin liquid layer. In the first scheme, a thick layer of a liquid, e.g. flibe, is formed inside the chamber solid walls to form a "pocket" surrounding the microexplosion. This scheme has the added advantage of also protecting the first wall from neutron damage. Examples of key issues associated with this scheme are:

1) the ability to form a stable and uniform thick liquid layer so as to fully cover the interior surfaces of the first wall,;
2) the feasibility of forming the liquid layer so as to allow holes for the driver beams without exposing the first wall to unacceptable levels of X-rays and debris;
3) the ability to re-establish the wall protection layer after the microexplosion; and
4) the need for this liquid to contain lithium to provide adequate breeding and the ability to clear the chamber from a multi-species liquid (e.g. the molten salt flibe).

Another scheme for wall protection relies on a thin liquid metal film wetting the first wall. This concept allows greater control over liquid feeding and uniformity of the liquid layer. It can use a single-element liquid; for example, lead, which is a neutron multiplier that can also enhance tritium breeding. Examples of issues with this scheme are: a) blast effects, b) flow around geometric perturbations, c) neutron damage and activiation, and d) protection of inverted surfaces. Only a very small effort has been devoted to this critical issue of wall protection. Experiments and modelling are needed to evaluate the scientific and technological issues—fluid mechanics, thermomechanics, and materials response—of the various wall protection schemes.

The second IFE issue is cavity clearing at IFE pulse repetition rates. Following each pellet explosion, the cavity (chamber) fills with target debris and material evaporated or otherwise ejected from the cavity surfaces. This material must be removed from the cavity before the next target is injected. This generally requires recondensing condensable gases onto the surfaces of the first wall (or more specifically the surfaces of the wall protection layer) and by pumping non-condensable gases out through large ducts. Power reactors require a repetition rate of ~3–10 pulses per second. Evacuation requirements depend on propagation limits for both targets and driver energy. Base pressure requirements: determine 1) the time to evacuate the chamber; and 2) the level of protection to the first wall (and final optics) afforded by the cavity background gas. Research is needed to better understand clearing requirements, the recondensation process, and to develop design solutions. Some small scale experiments are being planned at universities.

The remaining fusion chamber and target fabrication issues in Table 1 are related strictly to power plant technology feasibility, safety, and economics. They include: demonstration of tritium self-sufficiency in a practical IFE system; demonstration of adequate radiation shielding of all components; thermo-mechanical response and radiation damage of the first-wall/blanket; and demonstration of low cost, high volume target production techniques. The required R&D and the resolution of these last four issues will be greatly influenced by the results of research to resolve the previous issues.

Synergy of IFE/ICF and MFE

- There is an important synergy in plasma theory and computer modeling as seen in the numerous books on plasma physics; e.g., in such areas as Particle-in-Cell simulations and intense radiation-plasma interactions
- Non-linear plasma instabilities, shock waves and implosion codes, non-neutral plasmas, plasma-wall interactions, and intense ion-beam physics are important common interests
- There is much in common in atomic physics and diagnostic needs, notably in the radiation detection area—mirrors, photo-detectors and lasers.
- Common technology interests include neutron damage resistant materials development and tritium breeding blanket technologies.

ACRONYMS

DOE	Department of Energy
DP	Defense Programs
DPSS(L)	Diode Pumped Solid State (Laser)
ER	Energy Research
ESTA	European Science and Technology Assembly
EU	European Union
FEAC	Fusion Energy Advisory Committee
FESAC	Fusion Energy Science Advisory Committee (The renamed FEAC June 1996)
G	Target Energy Gain
GIMM	Grazing Incidence Metal Mirror
HIF	Heavy Ion Fusion
ICF	Inertial Confinement Fusion
ICFAC	Inertial Confinement Fusion Advisory Committee
IFE	Inertial Fusion Energy
ILSE	Induction Linac System Experiments
IRE	Intermediate Research Experiment
ITER	International Thermonuclear Experimental Reactor
kJ	kiloJoule
KrF(L)	Krypton Fluoride (Laser)
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MFE	Magnetic Fusion Energy
MIT	Massachusetts Institute of Technology
MJ	MegaJoule
NIF	National Ignition Facility
OFES	Office of Fusion Energy Sciences
PPPL	Princeton Plasma Physics Laboratory
RF	Radio Frequency
SNL	Sandia National Laboratories
TFTR	Toakamak Fusion Test Reactor

Department of Energy
Washington, DC 20585

Dr. Robert W. Conn, Chair
Fusion Energy Advisory Committee
School of Engineering
University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0403

Dear Dr. Conn:

This letter forwards the charge that follows up on a specific recommendation made by your Committee in its report. “A Restructured Fusion Energy Sciences Program.” The report calls for a programmatic review to assist the Department in setting technical priorities for the Inertial Fusion Energy (IFE) Program.

Inertial fusion has been reviewed often in the past decade, including the Fusion Policy Advisory Committee in 1990, the Fusion Energy Advisory Committee (FEAC) in 1993, as well as two reviews by the National Academy of Sciences during the 1980s. Questions of scientific merit and appropriate energy relevance have been addressed positively by the previous reviews. For the near term, however, we would like you to provide us with an assessment of the content of an inertial fusion energy program that advances the scientific elements of the program and is consistent with the Fusion Energy Sciences Program, and budget projections over the next several years.

Please consider augmenting the expertise of FEAC with appropriate individuals from inertial fusion programs that are active in this country, as well as foreign participants that would be helpful.

I would like to have your recommendations regarding this program by July 1996.

The Department is appreciative of the time and energy provided by the members of FEAC in this continuing effort to improve and orient the fusion energy sciences program to the needs of the times. I will look forward to hearing the Committee’s recommendations on this matter.

Sincerely,

Martha A. Krebs
Director
Office of Energy Research

Charge to the Fusion Energy Advisory Committee for an Inertial Fusion Energy Review

Since 1990, the fusion program has had a mandate to pursue two independent approaches to fusion energy development, magnetic and inertial confinement fusion. In magnetic fusion, our strategy is to continue to use international collaboration, especially participation in the International Thermonuclear Experimental Reactor, to pursue fusion energy science and technology. In inertial fusion, our strategy has been to assume the target physics is the highest priority activity and would be developed as a part of the weapons research program; and, indeed, the next step in the development of target physics, namely the National Ignition Facility, is proceeding into construction in Defense Programs.

Based on the Fusion Policy Advisory Committee report of 1990, we had taken as our highest priority in inertial fusion energy the development of heavy ion accelerators as the most desirable driver for energy applications. That development program has met all of its milestones and has received numerous positive reviews, including one by the Fusion Energy Advisory Committee (FEAC), which in 1993 recommended a balanced Inertial Fusion Energy program of heavy ion accelerator development, plus other smaller scale efforts, at $17 million per year.

The potential for inertial fusion energy has been judged to be real, but the fusion program no longer has as a goal the operation of a demonstration power plant by 2025. Given that the basic mission of the fusion program has changed from energy development to fusion energy science, and that funding for the entire fusion program will be constrained for some number of years, I would like FEAC to again consider inertial fusion energy and recommend what the new Fusion Energy Sciences program should be doing in support of this future fusion application, and at what level?

July 17, 1996

Professor Robert W. Conn
Dean
School of Engineering
University of California, San Diego
9500 Gilman Drive
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Dear Professor Conn:

In May, you sent me by fax a copy of the charge to the Fusion Energy Sciences Advisory Committee (FEAC) from Martha Krebs, regarding the Inertial Fusion Energy (IFE) program of the Office of Fusion Energy Sciences. Enclosed is a copy of the Charge.

The panel of technical experts (see Enclosure 2) that I chaired held two meetings in June, one at the Lawrence Berkeley National Laboratory and one at the Lawrence Livermore National Laboratory. We received input from DOE/OFES and DOE/DP/ICF and from numerous experts from the many institutions involved in inertial fusion research.

The new mission of the OFES is to “Advance plasma science, and fusion technology—the knowledge base necessary for an economically and environmentally attractive energy source for the nation and the world.”

Because of the short time given to respond to this charge, we decided to rely on background information contained in the FEAC-7 report of a more extensive review of this subject published in 1993, and to hear mainly about programs since that time.

Our panel has the following findings:

(1) Progress in the IFE program since the 1993 FEAC-7 review has been good, despite its being funded at the $8 million per year level, rather than the then-recommended $17 million level.

(2) A strong IFE program is a proper and important component of the restructured OFES/DOE program. Challenging and relevant scientific issues need to be resolved, notably in collective effects in high current accelerators and beam-plasma interactions.

(3) With DP/ICF physics development and supporting science and technology and the high repetition rate driver development in the OFES/IFE program, the United States is positioned to lead the world in IFE science and technology.

(4) There has been significant progress since 1993; a substantial declassification in the DP/ICF area allows wider participation and more rapid scientific progress; in progress in preparation for the National Ignition Facility (NIF); in target physics, heavy ion accelerator technology; in operation of improved laser systems; operation of light-ion systems; and in improved understanding of power plant issues.

(5) The inertial fusion program involves much exciting science and technology, and there are opportunities because of declassification to broaden the work in the IFE program. The work of LBNL, LLNL and the institutions is of high scientific gravity.

(6) There are numerous challenges in physics and technology but there are no show-stoppers.

(7) The time frame is set by a succession of anticipated events in the DP and the OFES programs. In the restructured OFES program, it is envisaged that there will be “a growing portfolio of new experiments.” By 1999, the International Thermonuclear Experimental Reactor Engineering Design Activities will be complete, if the presently proposed schedule is followed the NIF should be well advanced in its construction phase, and the Tokamak Fusion Test Reactor program at the Princeton Plasma Physics Laboratory will be completed. This is a period in which some new initiatives—including one in IFE—should be ready for consideration by OFES. The NIF program is designed to have the capability to ignite a D-T target in the 2005 time frame.

(8) The heavy ion driver is the most promising for energy applications because of its greater efficiency, about 3 times greater than laser driver candidates. Further, the induction linac approach is the most likely to meet performance/cost targets.

In the longer term, breakthroughs in the development of laser systems could change these conclusions, and reassessments should be made on a regular basis.

(9) There is a need for an Integrated Research Experiment (IRE) to have in one facility the ability to resolve basic beam dynamics, final beam focusing and transport issues in a reactor relevant beam parameter regime, and to evaluate the target heating phenomonology. Progress in beam development encourages the belief that the conceptual design of a 3kJ–30kJ, ∼100 MeV driver could be developed around 1999, provided there is continued support for accelerator development.

(10) Target physics will not be tested conclusively before the experiment on NIF. LLNL has just completed an integrated simulation of a heavy ion driver target. It is important for other groups to develop new codes and to perform independent confirmatory simulations. Such efforts, would provide an important link between the MFE and the IFE communities.

(11) Several comprehensive conceptual design and system studies have been completed. They show the potential for and the requirements for IFE to provide competitive power plants. The IFE program within OFES should have sufficient breadth beyond driver development to cover those other areas that are critical to its feasibility and competitiveness.

As a first priority, we suggest work on wall protection scheme evaluations and development and confirmatory simulations of heavy ion driver performance. As a second priority, there should be work on cavity clearing technologies at IFE repetition rates and the development of final focusing optics for lasers (we assume that focusing and transport work for beams will be undertaken as a part of the accelerator development program.) As a third priority, work on target factory studies, rep-rated laser systems (a promising area but the present funding level will only support development of the most promising driver), shielding, blanket and tritium studies, and further detailed power plant conceptual design studies.

(12) We suggest that a joint IFE steering committee, between ER and DP, consisting of all interested parties, should review the program on a regular basis, and define the expectations for the ER and DP parts of the program. In addition, this steering committee could facilitate international collaboration.

(13) The position of the Panel is that there should be an increase in the non-driver part of the IFE program, raising it from the present ∼$1M per year to $2–3M per year. It is noted that if this were done at a constant level of about $8M per year it would substantially slow the pace of accelerator development. In fact, the FEAC-7 report identifies the $5M per year case as one in which there is no credible program for the development of a heavy ion fusion energy option. The following finding, concerning funding for the IFE program, represents a medial opinion of the Panel. A minority of the Panel would support a more aggressive approach and a comparable minority, a less aggressive approach.

The medial opinion is that funding for the IFE program should be increased to about $10M per year for the next few years to strengthen the scientific and technological understanding of the prospects of IFE and to involve a wide range of institutions in these efforts. Such an annual budget would allow maintaining the pace of heavy ion accelerator development. In total, the program would provide the breadth of support necessary for initiation around the year 2000 of a construction project for an integrated research experiment using a multi-kJ heavy ion driver with a target chamber. An increased budget in the 1999 time frame would be required for developing such a proposal.

Sincerely,

/s/John Sheffield
Chair, on behalf of the FEAC/IFE panel

Dr. Martha Krebs
Director
Office of Energy Research
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

July 17, 1996

Dear Dr. Krebs:

The Fusion Energy Science Advisory Committee (FESAC) transmits to you the report of the FESAC Inertial Fusion Energy Panel, formed to address the issues you raised in your charge letter to me this past April. The Panel, chaired by Dr. John Sheffield, prepared this comprehensive report in a short time and we acknowledge with appreciation all the work of the Panel members.

The FESAC has reviewed and discussed the Panel's findings and funding recommendations, and we support them on the assumption that the President's budget request is approved. The Panel finds that Inertial Fusion Energy (IFE) research is scientifically and technically challenging and fits appropriately as a part of the restructured fusion program. The Panel also finds that the IFE program now conducted by the Office of Fusion Energy Sciences of Energy Research benefits from an "essential symbiotic relationship with the Inertial Confinement Fusion (ICF) program conducted by Defense Programs." The Panel recommends that a joint IFE steering committee between Energy Research and Defense Programs be formed to review the IFE program and related programs in Defense Programs on a regular basis, to ensure strong coordination.

The Panel accepts the findings and recommendations of earlier reports about the heavy ion beam development program. The Panel recommends that $2 million to $3 million per year be devoted to non-driver science and technology, with highest priority (beyond heavy ion driver development) being wall protection and cavity clearance schemes and confirmatory simulations of heavy ion driver target performance. The Panel notes that if the budget were to remain at the present level of about $8 million per year, the pace of development of the heavy ion accelerator would be substantially slowed.

The Panel, while not unanimous about the appropriate budget level, indicates that the budget for the IFE program should be increased to about $10 million per year for the next few years to resolve both driver and non-driver issues. This would allow the program to make an informed decision on whether to proceed with a full heavy ion driver and target experiment in three to four years while increasing the breadth of the program. FESAC recommends that a final judgement on the proper budget level and program balance await final resolution of the FY 1997 budget for OFES programs.

Sincerely,

Robert W. Conn
Chairman, on behalf of the
Fusion Energy Sciences
Advisory Committee