CHAPTER 1
INTRODUCTION

The Department of Energy, Office of Fusion Energy, contracted with McDonnell Douglas Aerospace (MDA) and its subcontractors to develop and assess two separate Inertial Fusion Energy (IFE) reactor design studies. A parallel effort with identical goals and direction was also funded and contracted to W. J. Schafer and Associates. DOE wanted in-depth design studies similar to those previously accomplished in Magnetic Fusion Energy (MFE) to advance the state-of-the-art of IFE physics, technology, and engineering. These studies will provide a basis for future R&D planning to achieve successful commercialization of inertial fusion. The teams were encouraged to seek innovative design approaches and cost-effective solutions while improving the safety and environmental impact aspects of the reactor designs. Since there are several attractive IFE driver technologies, the teams had the opportunity to choose two drivers to be used in two conceptual reactor design studies. The driver technologies chosen by both teams during the pre-proposal efforts were the KrF laser and the heavy ion beam.

The 18-month MDA study ran from September 1990 to March 1992. Difficulties in the subcontract approvals delayed full team involvement until February 1991; however, all project milestones were met.

The program objectives were clearly defined in the contractual statement of work (SOW). The main objectives are summarized below:

- Adopt common groundrules for design development and comparison tasks
- Conduct parametric trades studies using developed systems codes
- Develop conceptual designs for two IFE reactor power plants
- Estimate plant capital and operating costs
- Assess critical technical issues and define R&D requirements
- Compare two IFE reactor designs
- Document the results

Accomplishment of these objectives in a timely and cost-effective manner required an experienced, multi-disciplined team of individuals and companies intimate with the IFE technologies and reactor design. McDonnell Douglas Aerospace assembled an exemplary team with outstanding capabilities.

Company/University	Area of Responsibility
McDonnell Douglas	Program management, systems integration, system analysis, costing
Canadian Fusion Fuels Technology Project (CFFTP)	Design of the fuel system, tritium inventory assessment
Ebasco Services	Energy conversion, safety and environmental impact assessment, balance of plant definition
KMS Fusion	Target and target-related systems, target factory
SPAR Aerospace Ltd.	Remote maintenance systems; reliability, availability, maintainability
TRW, Space & Electronics Group	KrF and heavy ion driver systems
University of California, Los Angeles	Reactor cavity design and analysis - first wall, blanket, shield, final optics (lifetime), safety
Dr. Mohamed Abdou	Technical Consultant on comparison and evaluation methodology, reactor design approach, economics, safety and environmental assessment

The Department of Energy commissioned an Oversight Committee to help provide technical guidance for the study team. Two subteams were formed. One subteam provided the overall reactor technical, economic/safety, and economic groundrules while the other subteam, the Target Working Group, provided unclassified, normalized data on laser and heavy ion target performance. These groups provided the study team with a set of recommended guidelines. Throughout the effort, the study team worked closely with the members of the Oversight Committee to clarify and enhance the reactor and target guidelines.

The study team enhanced and amplified the furnished guidelines to form a credible technical basis upon which to develop the conceptual design on a consistent basis with previous MFE and IFE designs as well as the W. J. Schafer-developed designs. Details of these requirements, guidelines and assumptions will be furnished in Chapter 3.

The ability of a study team to conduct system level trade studies to select the optimal system choices and operating parameter space is totally dependent upon having a credible systems analysis code. The code must be able to model with a reasonable fidelity the physics, technical performance, system efficiency, and cost of all the reactor plant systems and facilities. Fortunately, our team had the MDA ICCOMO systems analysis code from the Heavy Ion Fusion Systems Assessment (HIFSA) project[1] to build upon. Updates of the driver modeling were developed from data obtained from LANL and TRW on the laser driver and from LBL and TRW on the heavy ion driver. This code enabled trade studies that did not just find local minima or maxima of a particular system, but rather represented system effects which influenced the whole of the reactor plant usually in terms of the cost of electricity (COE).

The selection of the system options and the design parameter point was based upon a balance of several considerations. The system level trade study results were used to obtain the relative cost and performance factors. These were evaluated and compared to the technical and physics risk and the safety/environmental impact of the options being considered. Once the system options were selected, the systems analysis code provided further system optimization.

The conceptual design development for the two reactor designs was conducted in a phased manner to better utilize the available personnel and resources. The KrF driver reactor was completed first, with the heavy ion driver next. Dr. David Harris of Los Alamos provided assistance on the angular-multiplexed, large-area, e-beam pumped, laser amplifiers. The other laser driver option considered was the non-linear optical (NLO) system with smaller discharge lasers. The NLO system with discharge lasers was chosen as the baseline design because of the higher reliability and improved safety of the discharge lasers and the design flexibility of the NLO system.

An overriding concern in the heavy ion driver reactor designs is the cost of the driver that usually dominates the plant costs. The more conventional approach for the linear accelerator (linac) is to accelerate multiple beams to control space charge effects present in the beams; however, this approach is usually very expensive. LLNL is investigating the use of a recirculating linac to reduce its cost, but the recirculating LINAC represents a technology with a high degree of technical risk. Al Maschke of TRW conceived an approach to use a single beam LINAC rapidly pulsed to deliver multiple beams. These beams are temporarily stored in individual storage rings until they are simultaneously delivered to the reactor and target. We believe this approach represents a significant cost reduction in the LINAC and will provide the basis for a cost-effective reactor.

The Target Working Group (TWG) provided the study teams with technical guidelines of direct and indirect drive (DD and ID) targets for the laser driver and indirect drive for the heavy ion beam driver. This technical data consisted of gain and power curves, illumination requirements, pulse shaping, and pulse duration. Building upon the data provided, it was determined that the direct drive laser target and the indirect drive heavy ion target would be best suited for use in the design studies.

The reactor cavity is a key element in the overall design of an inertial fusion power plant. The design of the cavity elements is significantly different from those of magnetic fusion. There is much more design freedom because of the lack of the constraints imposed by toroidal and poloidal field coils and the shaping of the cavity wall to coincide with critical field lines. The inertial cavity designer is freed from those severe constraints. However inertial confinement imposes new design constraints in terms of pulsed operation, severe electromagnetic and blast effects, and beamline penetrations. The previous inertial fusion cavity design approaches were evaluated for incorporation along with other promising new design concepts. The adopted reactor cavity design is a blend of new concepts, modifications of previously proposed IFE designs, and adaptations of MFE technologies. A layer of liquid lead protects a silicon carbide (SiC) first wall structure containing coolant channels of flowing liquid lead. In addition to protecting the first wall, the liquid lead vacuum pumps the chamber, providing the requisite base pressure between target implosions. Behind the first wall is a low-pressure, helium-cooled breeding blanket. The breeding material, Li_2O, is housed in a low-activation SiC blanket structure. The vacuum vessel and shield are composed of ferritic steel, H_2O, B_4C, Pb, and SiC. This is a very low activation design which is beneficial in terms of environmental impact. The low pressure helium coolant provides a high degree of safety due to passive containment of the coolant in the event of a coolant tube rupture.

The reactor cavity design team assessed all the reactor cavity design options for both driver options, fully anticipating that two separate designs might evolve. Rather, it was found that the design for the KrF driver has the more severe requirements in terms of lower cavity pressure and more beam penetrations. Therefore the resultant design for the KrF driver will be appropriate for the heavy ion driver case.

The remainder of the reactor equipment systems and balance of plant (BOP) systems were developed with the intent of being used in both reactor concepts with suitable modifications. The driver building design will be unique for each driver concept.

One of the most important outputs of the study is the identification and assessment of the resultant technical issues. The project team first identified specific technical issues that must be addressed and solved for each reactor system. Research and development needs were defined for each of the technical needs. To provide additional information, the list of key issues was reviewed, summarized, and condensed to those critical issues that were of most importance to the advancement of commercial inertial fusion energy.

A quantitative methodology for the comparison and evaluation of the two reactor designs was developed. The general evaluation parameters are as follows:

- Physics Feasibility
- Engineering Feasibility
- Economics
- Safety and Environmental Impact
- R&D Requirements

The two reactor concepts are quantitatively scored in each category which is appropriate at this developmental stage. As fusion technology advances, both the physics and the engineering feasibility questions will be answered by the necessary R&D efforts. Time to accomplish the R&D is also implicitly included in the R&D requirements. Thus the evaluation of the reactor concepts will ultimately be measured by economics and safety/environmental impact. Even the safety/environmental impact could be assessed in economic terms. For the present, it is prudent to retain all the evaluation parameters. Because of the diverse nature of the parameters and their relative perception by factions, there will not be an overall total weighted score. It will be left to the reader to judge the relative merits of each concept in each general evaluation area.

The endeavor of developing two separate IFE reactor conceptual designs within the same study using identical groundrules and requirements has been enlightening. The study may provide DOE and the fusion community with innovative and cost-effective solutions. However, many of the key technical issues remain to be identified and resolved.

Reference for 1

1. D. S. Zuckerman, et al., "Induction Linac Driven Heavy Ion Fusion System Model," Fusion Technology, Vol 13, #2, 1986.