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DESIGN CONSIDERATIONS FOR AN INERTIAL-
CONFINEMENT FUSION-REACTOR POWER PLANT

J. E. Simpson
J. V. Massey

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REACTOR POWER PLANT

by

J. V. Massey and J. E. Simpson

Bechtel Group, Inc.
San Francisco, CA 94111

To further define the engineering and economic concerns for inertial confinement fusion reactors (ICR's), a conceptual design study was performed by Bechtel Group Incorporated under the direction of Lawrence Livermore National Laboratory (LLNL). The study examined alternatives to the LLNL MYLIFE ⁽¹⁾ concept and expanded the previous balance of plant design to incorporate information from recent liquid metal cooled fast breeder reactor (LMFBR) power plant studies ⁽²⁾. The majority of the effort was to incorporate present laser and target physics models into a reactor design with a low coolant flowrate and a high driver repetition rate. An example of such a design is the LLNL JADE* concept ⁽³⁾. In addition to producing a power plant design for LLNL using the JADE example, Bechtel has also examined the applicability of the EAGLE (Energy Absorbing Gas Lithium Ejector) concept ⁽⁴⁾.

The baseline design is for a twin-unit power plant with each unit having an electrical output of 1000 MWe. The design provides for two separate reactor-turbine power plants, driven by a single 4.4 MJ laser pulsed at 10 Hz (5 Hz to each reactor). The site also contains a tritium target manufacturing facility and all appropriate auxiliary, miscellaneous, and waste handling facilities. The primary design areas that were addressed are: reactor concept, heat transfer system, beam transport system, balance of plant, and capital cost.

* Name only, not an acronym.

Three reactor concepts were compared in this study. The HYLIFE reactor uses high flowrate lithium jets to absorb the fusion energy and protect the first structural wall. The high flowrate (~ 10 times than that needed for a typical temperature rise of $\sim 150^\circ\text{C}$) requires numerous large pumps and, hence, requires a large and costly containment building ^(1,3). The JADE reactor utilizes a novel concept of porous metal, cellular structures to "hold up" slow flowing lithium in front of the first structural wall. The slow flow of the lithium in the porous metal allows for the desired temperature rise ($\sim 150^\circ\text{C}$) in the reactor vessel and for low pumping requirements ⁽³⁾. The EAGLE concept uses a flowing background gas and a lithium spray along the walls of an internal blast shield to absorb the fusion X-rays, target debris, and their secondary radiations. A liquid lithium blanket, behind the blast shield, absorbs neutrons and protects the structural wall. The overall liquid metal flowrate is set by the desired temperature rise and, hence, like the JADE reactor, the EAGLE requires a much lower flowrate than the HYLIFE ⁽⁴⁾.

A preliminary comparison of the three designs shows that a low flowrate reactor (such as the JADE and EAGLE concepts) offers substantial building size reductions and economic benefits over the HYLIFE design. However, more research on these new concepts is required to further justify their applicability and performance, and to more accurately compare the concepts.

A two loop lithium primary system (two pumps and four intermediate lithium-sodium heat exchangers - IHX's) was determined to be the best performer for the low flowrate reactors. The HYLIFE concept requires ~ 16 primary flow loops (16 pumps and 4 IHX's) to provide adequate wall protection. The use of lithium-lead as a primary coolant was also examined to reduce the hazards associated with liquid lithium, but the added problems of

pumping, pipe support, and toxicity were found to overshadow any safety advantage. The use of heat pipes for the primary and/or secondary heat removal system was examined for applications in the JADE reactor concept, but the combined limits of allowable vapor velocity, number and size of pipes and usable heat transfer area precluded the practical applications of these devices. The reduction of the 4 loop sodium secondary system to a 2 loop lithium system was not justified because the system would still require 4 steam generators (without large extrapolations from present steam generator designs). Furthermore, they would have to be designed as lithium to water steam generators, requiring a significant developmental program.

Two alternative beam transport systems were examined in this study. The first provides two-sided illumination of the target as used in the previous HYLIFE designs. The second provides symmetrical, eight-sided illumination of the target. The eight-sided illumination requires more evacuated beam tunnel volume, more mirrors, a larger containment building, and subsequently a larger capital cost. However, it is expected that the eight-sided illumination would produce improved laser-target performance and might reduce laser power requirements and, hence, reduce laser capital cost. Further study will be required to determine the exact economic and performance trade-offs between number-of-beams and laser power.

The balance of plant for the ICR was modeled, as much as possible, after the current LMFER design ⁽²⁾. The ICR design includes unique primary and secondary piping and equipment layouts for the two and eight sided illumination cases. Conceptual designs for containment buildings, optical cells, beam tunnels, steam generator buildings, turbine generator buildings, laser buildings, target fabrication buildings and other essential maintenance and operating buildings were established. Miscellaneous support buildings

and the overall plot plan was modeled directly from the LMFBR design.

The economic analysis of ICR power plant designs (both JADE and EAGLE, with two/or eight-sided illumination) shows marked improvement over HYLIFE plant designs (capital cost reductions by as much as 20%). The main areas of cost reduction were in the primary heat transfer system equipment (reduced from 16 primary pumps to two of similar size and design) and reactor containment building size (reduced by $\sim 1/2$).

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