Initial Results from ARIES-IFE Study and Plans for the Coming Year

Farrokh Najmabadi for the ARIES Team

Heavy-ion IFE Meeting

July 23-24, 2001
Lawrence Livermore National Laboratory

Electronic copy: http://aries.ucsd.edu/najmabadi/TALKS
ARIES Web Site: http://aries.ucsd.edu/ARIES
ARIES-IFE Goals and Plans

- Program started in June 2000 ($400k in FY00, $1.1M in FY01)

Initial Results

- Accurate target output spectrum has been produced.
- Assessment of Dry-wall chambers is near completion.
  - Dry-wall chambers appears feasible for both lasers and heavy ion drivers (only outstanding issue is heavy-ion transport in the gas-filled chambers)
  - Self-consistent system parameters have been developed.
- Assessment of “Wetted-wall” chambers is in progress.

Plans for FY2002
ARIES Integrated IFE Chamber Analysis and Assessment Research -- Goals

- Analyze & assess integrated and self-consistent IFE chamber concepts
- Understand trade-offs and identify design windows for promising concepts. *The research is not aimed at developing a point design.*
- Identify existing data base and extrapolations needed for each promising concept. Identify high-leverage items for R&D:
  - What data is missing? What are the shortcomings of present tools?
  - For incomplete database, what is being assumed and why?
  - For incomplete database, what is the acceptable range of data? Would it make a difference to zeroth order, *i.e.*, does it make or break the concept?
  - Start defining needed experiments and simulation tools.
ARIES-IFE Is a Multi-institutional Effort

OFES

Advisory/Review Committees

Program Management
F. Najmabadi
Les Waganer (Operations)
Mark Tillack (System Integration)

Executive Committee
(Task Leaders)

Tasks

- Target Fab. *(GA, LANL*)
- Target Inj./Tracking *(GA)*
- Materials *(ANL)*
- Tritium *(ANL, LANL*)
- Drivers* *(NRL*, LLNL*, LBL*)
- Chamber Eng. *(UCSD, UW)*
- CAD *(UCSD)*
- Target Physics *(NRL*, LLNL*, UW)*
- Chamber Physics *(UW, UCSD)*
- Parametric Systems Analysis *(UCSD, BA, LLNL)*
- Safety & Env. *(INEEL, UW, LLNL)*
- Neutronics, Shielding *(UW, LLNL)*
- Final Optics & Transport *(UCSD, NRL*, LLNL*, LBL, PPPL, MRC)*

* voluntary contributions
An Integrated Assessment Defines the R&D Needs

- Target Designs
- Chamber Concepts
- Target fabrication, injection, and tracking
- Chamber environment
- Final optics & chamber propagation
- Chamber R&D: Data base Critical issues

Characterization of target yield
Characterization of chamber response

Driver

Assess & Iterate
We Use a Structured Approach to Assess Driver/Chamber Combinations

- Six classes of target were identified. Advanced target designs from NRL (laser-driven direct drive) and LLNL (Heavy-ion-driven indirect-drive) are used as references.

- To make progress, we divided the activity based on three classes of chambers:
  - Dry wall chambers;
  - Solid wall chambers protected with a “sacrificial zone” (such as liquid films);
  - Thick liquid walls.

- We research these classes of chambers in series with the entire team focusing on each.
Six combination of target spectrum and chamber concepts are under investigation:

<table>
<thead>
<tr>
<th></th>
<th>Dry wall</th>
<th>Solid wall with sacrificial layer</th>
<th>Thick Liquid Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct drive target</td>
<td>Complete, Documentation</td>
<td>Work started in March 2001</td>
<td>*</td>
</tr>
<tr>
<td>Indirect drive target</td>
<td>Nearly Complete, Documentation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Probably will not be considered because of large number of penetrations needed
ARIES-IFE Goals and Plans

- Program started in June 2000 ($400k in FY00, $1.1M in FY01)

Initial Results

- Accurate target output spectrum has been produced.
- Assessment of Dry-wall chambers is near completion.
  * Dry-wall chambers appears feasible for both lasers and heavy ion drivers (only outstanding issue is heavy-ion transport in the gas-filled chambers which is under study)
  * Self-consistent system parameters have been developed.
- Assessment of “Wetted-wall” chambers is in progress.

Plans for FY2002.
## Energy output and X-ray Spectra from Reference Direct and Indirect Target Designs

<table>
<thead>
<tr>
<th></th>
<th>NRL Direct Drive Target (MJ)</th>
<th>HI Indirect Drive Target (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-rays</td>
<td>2.14 (1%)</td>
<td>115 (25%)</td>
</tr>
<tr>
<td>Neutrons</td>
<td>109 (71%)</td>
<td>316 (69%)</td>
</tr>
<tr>
<td>Gammas</td>
<td>0.0046 (0.003%)</td>
<td>0.36 (0.1%)</td>
</tr>
<tr>
<td>Burn product fast ions</td>
<td>18.1 (12%)</td>
<td>8.43 (2%)</td>
</tr>
<tr>
<td>Debris ions kinetic energy</td>
<td>24.9 (16%)</td>
<td>18.1 (4%)</td>
</tr>
<tr>
<td>Residual thermal energy</td>
<td>0.013</td>
<td>0.57</td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>458</td>
</tr>
</tbody>
</table>

X-ray spectrum is much harder for NRL direct-drive target.

- Detailed target spectrum available on ARIES Web site
  [http://aries.ucsd.edu/ARIES/WDOCS/IFE/]
Target Injection/Tracking Analysis Is Completed

- Analysis of design window for successful injection of direct and indirect drive targets in a gas-filled chamber (e.g., Xe) is completed.
  - No major constraints for indirect-drive targets.
  - Narrow design window for direct-drive targets (Pressure < ~50 mTorr, Wall temperature < 700°C)
Target injection Design Window Naturally Leads to Certain Research Directions

Target injection window
(for 6-m Xe-filled chambers):
Pressure < 10-50 mTorr
Temperature < 700 C

Chamber-based solutions:
- Low wall temperature: Decoupling of first wall & blanket temperatures
- Low gas pressure: More accurate calculation of wall loading & response
- Alternate wall protection Advanced engineered material
  Magnetic diversion of ions*

Target-based solutions: Sabot or wake shield, Frost coating*

* Not considered in detail
Variations in the Chamber Environment Affects the Target Trajectory in an Unpredictable Way

- Forces on target calculated by DSMC Code
- “Correction Factor” for 0.5 Torr Xe pressure is large (~20 cm)
- Repeatability of correction factor requires constant conditions or precise measurements
- 1% density variation causes a change in predicted position of 1000 µm (at 0.5 Torr)
- For manageable effect at 50 mTorr, density variability must be <0.01%.
- Leads to in-chamber tracking

Ex-chamber tracking system

- MIRROR R 50 m
- TRACKING, GAS, & SABOT REMOVAL
- STAND-OFF 2.5 m
- INJECTOR
- 7m STAND-OFF
- 2.5 m
- 6.5 m T ~1500 C
- ACCELERATOR 8 m 1000 g Capsule velocity out 400 m/sec
- TRACKING ACCURACY
- GIMM R 30 m
- CHAMBER R 6.5 m
- ACCURACY TRACKING
- INJECTOR
- 8 m 1000 g
- Capsule velocity out 400 m/sec
- INJECTOR ACCURACY
- GIMM R 30 m

Graph:

- Change from original position (microns)
- Pressure (mTorr) at 300 K
- Curves showing 0.01%, 0.1%, 1%, and 10% density variations
- Data points for each density variation level
Thermal Analysis of Chamber Wall

- Target spectrums were coupled with BUCKY Code to establish heat and particle flux on the wall and the operating windows.

- Time of flight of ions spread the temporal profile of energy flux on the wall over several $\mu$s (resulting heat fluxes are much lower than predicted previously).

- Use of an armor decouples survivability of first wall from efficient operation of blanket and allows much flexibility in systems and material choices.
  - We have considered W and C armor (10s to 100 $\mu$m thick). Other armor material is possible.
  - As an example, this armor is coupled to ARIES-AT blanket leading to $\sim$55% thermal conversion efficiency.
Use of an armor allows an Efficient IFE Blanket With Low Wall Temperature Is Possible

- As an example, we considered a variation of ARIES-AT blanket as shown:
- Simple, low pressure design with SiC structure and LiPb coolant and breeder.
- Innovative design leads to high LiPb outlet temperature (~1100°C) while keeping SiC structure temperature below 1000°C leading to a high thermal efficiency of ~55%.
- Simple manufacturing technique.
- Very low afterheat.
- Class C waste by a wide margin.
Dry-wall Chamber Survives the Energy Flux
NRL Direct Driver Target (160 MJ)

Graphite Chamber Radius of 6.5m

Max. Equilibrium Wall Temp. to Avoid Vaporization (°C)

Target injection/tracking design window

- There is no need for gas protection.
- Similar results are obtained for W armor.
Dry-wall Chamber Survives the Energy Flux
HIF Indirect Drive (458 MJ)

- Gas pressures of > 0.2 torr is needed (due to large power in X-ray channel).
- Similar Results for W.
Initial Results from ARIES-IFE have Removed Major Feasibility Issues of Dry Wall Chambers

- Work has also been performed on
  - Parametric variation of target yield and chamber size
  - Engineered Material
  - Final optics
  - Safety
  - A self-consistent set of device parameters is produced
  - Results will be presented at IFSA 2001

- Un-going activities in:
  - Heavy-ion propagation and focusing in gas-filled chambers
  - Recycling of hohlraum material
Recommendation to HIF Program

- Emphasize and vigorously support R&D on propagation and focusing of heavy-ion beam in gas-filled chambers.
  - It dramatically expands possibilities for HIF and makes it a much more attractive fusion option.
  - It leverages on much larger R&D on first-wall/blanket technology worldwide.
  - Final focusing magnets and their shielding impose severe constraints. Understanding trade-offs between different focusing techniques will greatly help optimization of HIF power plants.
Outline

- **ARIES-IFE Goals and Plans**
  - Program started in June 2000 ($400k in FY00, $1.1M in FY01)

- **Initial Results**
  - Accurate target output spectrum has been produced.
  - Assessment of Dry-wall chambers is near completion.
    - Dry-wall chambers appears feasible for both lasers and heavy ion drivers (only outstanding issue is heavy-ion transport in the gas-filled chambers which is under study)
    - Self-consistent system parameters have been developed.
  - Assessment of “Wetted-wall” chambers is in progress.

- **Plans for FY2002 and Beyond**
# Plans for FY 2002

- Assumes flat funding and division of resources between IFE and MFE studies.
- **IFE:** Complete ARIES-IFE study.
  - Indirect drive target: Nearly Complete, Documentation.
- **MFE:** Initial assessment of compact stellarators power plants in support of compact stellarator POP program (NSCX).
- This allows initiation of point design projects in either IFE or compact stellarators in FY03.