ABLATOR modeling of x-ray effects on liquid walls

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Outline

- Introduction
- Overview ABLATOR code
- ABLATOR calculations
- Future directions

Liquid walls for IFE

- Liquid wall chamber concepts use either a thin liquid layer (Prometheus, Osiris, HIBALL) to protect chamber from x rays and debris, or a thick liquid layer to also protect structures from neutron damage and activation (HYLIFE-II)

- Several issues have been identified in relation to the liquid wall behavior under the IFE threat spectra, and subsequent chamber clearing process

- It is important to understand the factors affecting the time required for liquid wall chambers to return to conditions that allow target injection and tracking and heavy ion beam propagation and focusing for the next shot

- **This talk focuses on the use of the LLNL's ABLATOR code as a predictive capability to assess liquid wall response to x-ray emission from IFE targets**

Overview of ABLATOR code

- The ABLATOR (“Ablation By LAgrangian Transient One-dimensional Response”) code is a 1-D finite difference code for the calculation of material response to x-rays

- In the Lagrangian scheme, zones and zone boundaries move with the material, as opposed to permitting mass flow between zones in a fixed grid (Eulerian); method guarantees mass conservation and is well suited to 1-D analyses (no mixing)

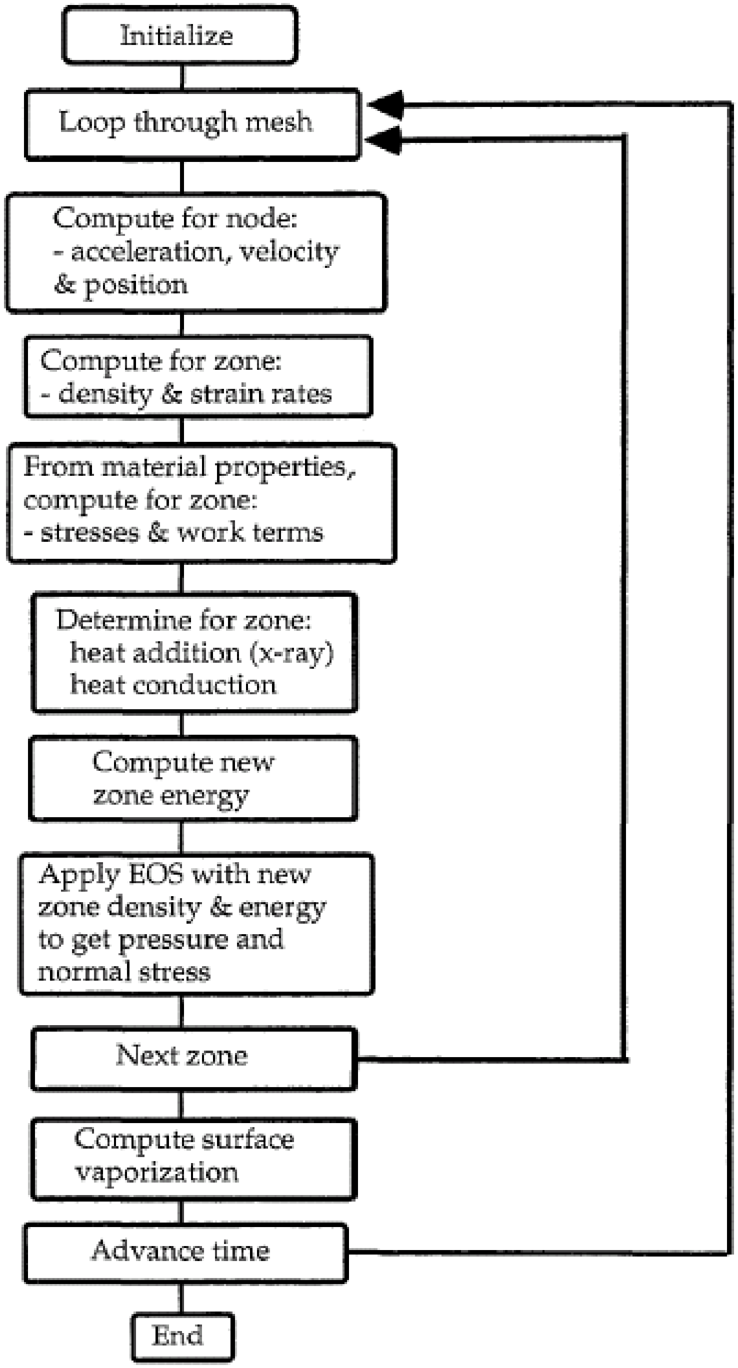
- The code uses an explicit scheme for advancing in time (conditions at the next time step are calculated directly from the state at the current time step plus any incremental energy input):
  - the advantage is that rapid and relatively simple calculations suffice to advance the solution
  - the major disadvantage is **numerical stability concerns**

The ABLATOR code capabilities

- X-rays from IFE targets deposit their energy in such small characteristic depths (~ 1 μm) that thermal conduction and hydrodynamic motion are significant effects on the nanosecond time scale

- Four processes are included in the ablation model:
  - energy deposition from the x-rays through the thin surface layers of material (x-rays of a particular photon energy deposit according to a simple exponential decay)
  - transient thermal conduction model allows this energy to move between zones (the one-dimensional planar equation of energy conservation is used to treat the internal energy of each Lagrangian zone, heat conduction between adjacent zones is calculated from the finite difference form of the Fourier heat conduction equation)
  - thermal expansion, which raises pressures and causes hydrodynamic motion (a finite-difference hydrodynamic model is implemented to track stress wave and material motion caused by the sudden energy deposition)
  - removal of material through surface vaporization and various spall processes

Flowchart for ABLATOR calculation



ABLATOR code main limitations

- No radiation model and no condensation model yet
- Code stability is of concern:
  - for an explicit method of time advance the time step size is limited by the stability condition: $\Delta t \leq (\Delta x)^2/2\alpha$,
  - other hydrodynamic stability requirements limit this step size such as maximum temperature change in a zone or in surface vaporization rate
  - if this conditions are not satisfied, unstable oscillations quickly develop
- Only cold opacities are used:
  - the attenuation in a zone at a given photon energy stays constant throughout the run
  - however, if a plasma is generated during x-ray deposition, the cold-opacity assumption breaks down: flibe case

Modifications introduced in the ABLATOR code

- Implemented direct-drive and indirect drive target spectra
- Introduced ability to account for attenuation through a background gas
- Added restart capability (read temperature/enthalpy profile from previous run)
- Modified to allow flexibility of user input (initial temperature, number and thickness of zones)
- Debugged/tested grazing incidence module
- Added tungsten to materials database
- Collaborated with UCSD to add flibe to the materials database
- Multi-material version of the code

Adding new materials to the data base

- Originally ABLATOR included Al, Alumina, Br, C, Cr, Silica, SiN, and SS409
- We have added W and flibe for direct- and indirect-drive IFE applications
- Two files are needed in order to run ABLATOR: the material properties file and the opacities file
- Materials properties file describes the thermodynamic properties, EOS of the material
- Opacities are given in 45 energy bins, from 1 eV to 100 KeV x-ray energies (could be changed rather easily)

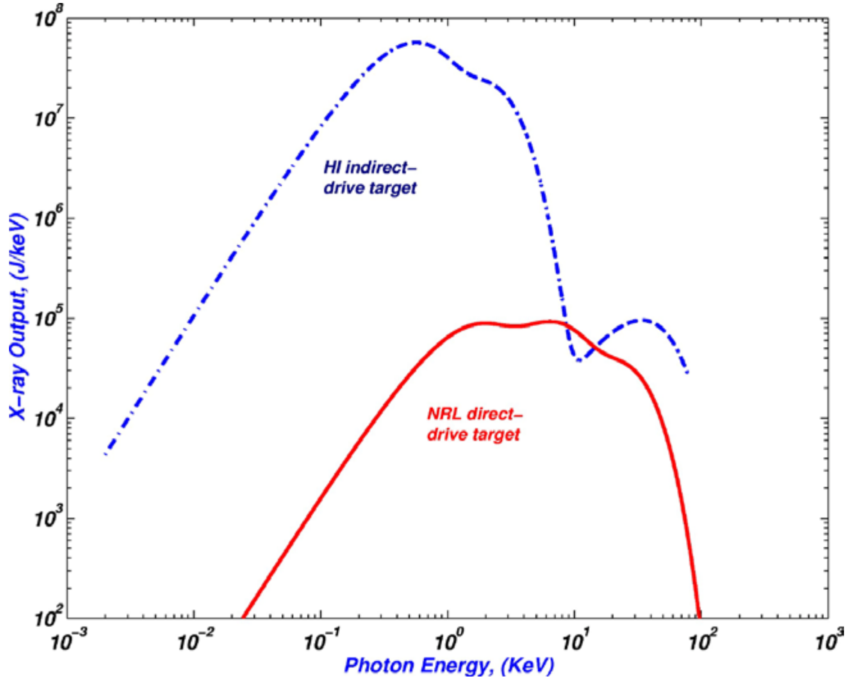
We have compared ABLATOR and TSUNAMI results for flibe

- Performed a series of runs for the case of a single energy line of 113 eV, 40 ns pulse at normal incidence, on flibe

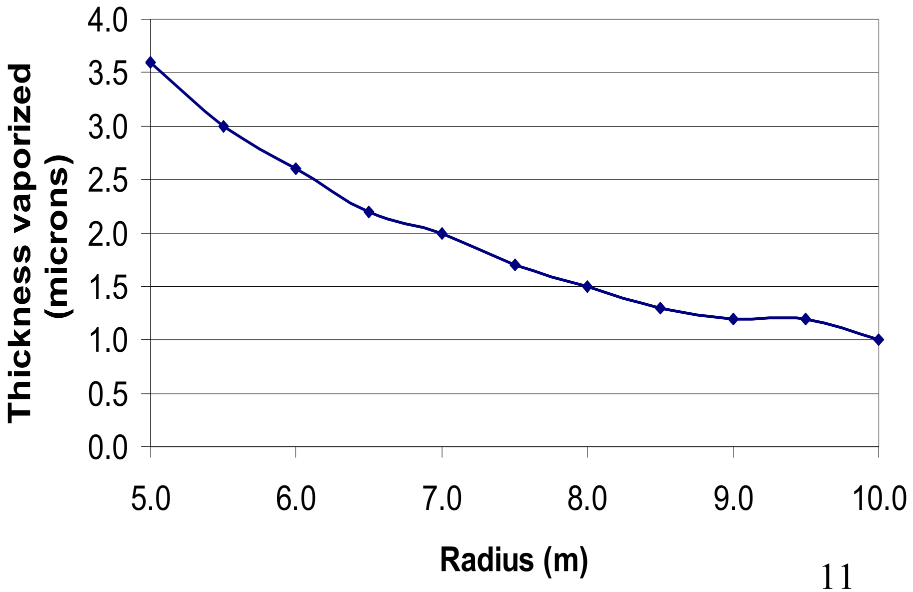
	Thickness vaporized	
Fluence (J/cm2)	Tsunami (microns)	Ablator (microns)
1	0.19	0.15
2	0.24	0.20
5	0.30	0.27
10	0.35	0.32
20	0.40	0.37
30	0.43	0.40

- Found very good agreement between the two codes, ABLATOR considers heat conduction during the pulse, whereas the energy deposition is instantaneous in TSUNAMI → slightly larger ablation depths

ABLATOR results for HIF spectrum



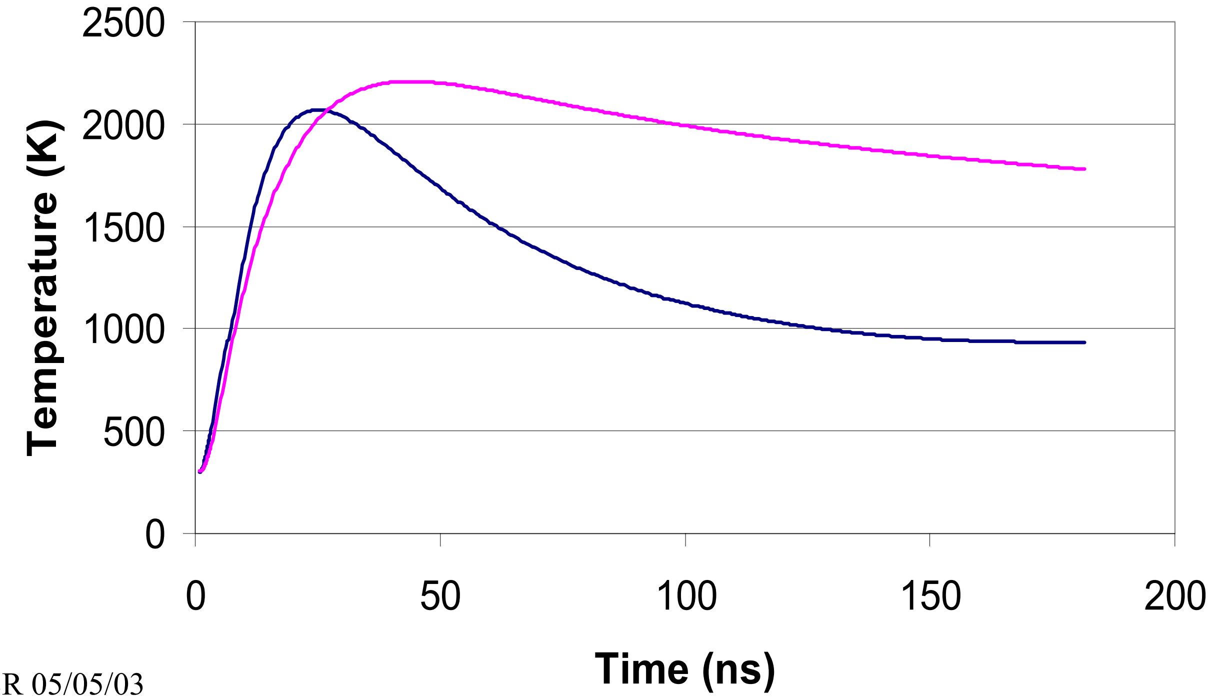
- We have obtained ablation thickness of the flibe under the real HIF spectrum for two cases:
  - Flibe pocket at 30 cm from target in thick liquid chamber
  - Flibe film at different distances from target in the case of a wetted wall



- We have estimated a total initial ablated thickness of 150 μm (~0.3 kg) in the case of the pocket and 2.2 μm (~2.3 kg) in the case of a wetted wall at 6.5 m

Optic damage in the case of laser indirect drive

- The x-rays from an indirect drive laser target could also damage the laser optic
- We have used ABLATOR to estimate the temperature history of an Al and a SiO_2 optic located at 30 m from the target (Al mirror is grazing incidence)



Note: Results very conservative as vacuum conditions were assumed

Conclusions

- We have updated the ABLATOR code for its use in IFE
- Materials data base now includes Flibe and tungsten
- Code has some limitations due mostly to numerical instability
- 113 eV results are very similar to those from TSUNAMI
- We have estimated ablation thickness for the cases of thick-liquid and wetted wall chambers
- Initial vaporized mass is ~ 0.3 kg for thick-liquid, ~ 2.3 kg for wetted wall (pocket is closer but surface area is smaller, whereas thin film is further from target but area is larger)

Future directions

- Benchmarking with other codes
- Other materials (SiC, ferritic steel, and other liquids – LiPb, Pb, LiSn, flinabe)
- Continue to investigate possibility of using XAPPER experiment for ablation & condensation studies/code validation
- Add ion stopping & heating
- Add roughening models for optics and dry walls
- Add radiation & condensation model (validation with UCLA experiment and others)