IFE Technology: Overview and Examples

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Dr. Michael Holland IFE Briefing
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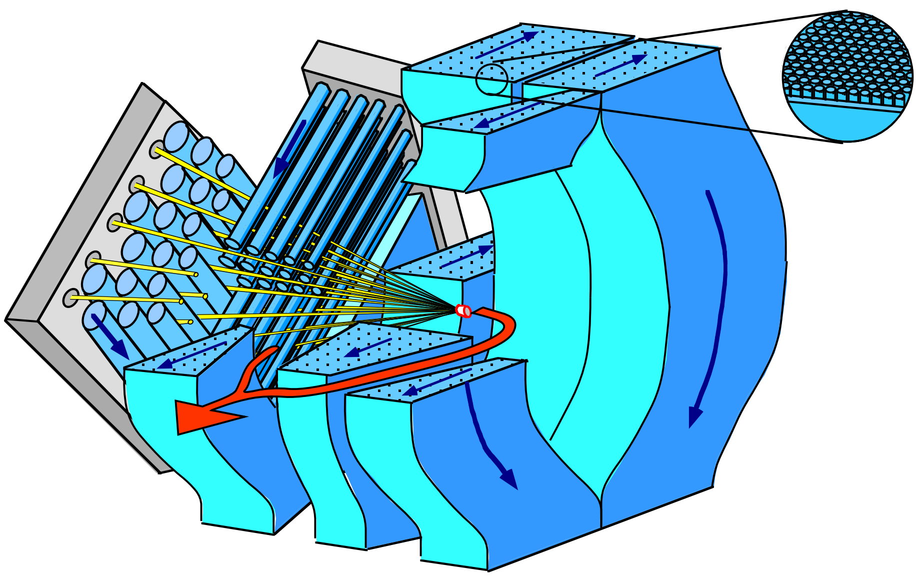


IFE Technology R&D falls into three broad categories

- **Scaling and integrated system modeling**
- **Phenomena modeling and experimental studies**
  - **Single effects experiments**
  - **Integral experiments for coupled phenomena**
  - **Model development and validation**
- **Supporting technology for experimental facilities**
  - **Component fabrication demonstrations and optimization**

IFE phenomena span an extremely wide range of scales

- **Time: 10^{-8} sec — 10^{9} sec**
  - **Target drive — chamber life time**
- **Length: 10^{-6} m — 10^{3} m**
  - **X-ray ablation layers — driver dimensions**
- **Temperature: 10 K — 10^{7} K**
  - **Cryogenic targets — post-ignition target debris**
- **Pressure: 10^{12} Pa — 10^{-1} Pa**
  - **X-ray ablation layers — pre-shot beam-line vacuum**
- **Matter states**
  - **Solid — liquid — vapor — ionized plasma**

Few topics share these scale extremes: Astrophysics, reactor safety analysis, global climate modeling… Complexity makes appropriate scaling methods essential

IFE system phenomena cluster into distinct time scales

Principal focus for IFE Technology R&D...

- **Nanosecond IFE Phenomena**
  - **Driver energy deposition and capsule drive (~30 ns)**
  - **Target x-ray/debris/neutron emission/deposition (~100 ns)**
- **Microsecond IFE Phenomena**
  - **X-ray ablation and impulse loading (~1 μs)**
  - **Debris venting and impulse loading (~100 μs)**
  - **Isochoric-heating pressure relaxation in liquid (~30 μs)**
- **Millisecond IFE Phenomena**
  - **Liquid shock propagation and momentum redistribution (~50 ms)**
  - **Pocket regeneration and droplet clearing (~100 ms)**
  - **Debris condensation on droplet sprays (~100 ms)**
- **Quasi-steady IFE Phenomena**
  - **Structure response to startup heating (~1 to 10^4 s)**
  - **Chemistry-tritium control/target fabrication/safety (10^3-10^9 s)**
  - **Corrosion/erosion of chamber structures (10^8 sec)**

*(Liquid-protected chamber example, dry wall is similar)

IFE † has intriguing complexity characteristics

- **Strong phenomena decoupling occurs in both time and space**
  - **Spatial decoupling boundaries**
    - » **small or unidirectional mass and energy fluxes**
    - » **large time scale differences—slow side sees integral effect of fast**
  - **Temporal decoupling boundaries**
    - » **large time scale differences —slower phenomena sees integral effect of fast**
  - **Inside these boundaries, phenomena interactions must be considered**
    - » **integral experiments must preserve key phenomena at reduced length/energy**
- **Interesting comparisons/contrasts**
  - **Nuclear and chemical process systems**
    - » **e.g. LWR large-break LOCA †**
  - **Environmental systems**
    - » **e.g. pollutant mixing in large ambients**
    - » **e.g. climate change modeling †**

S. Levy, 1999

† never tested at full scale, for various reasons...

Scaling provides a basis for selecting and designing IFE "integral" experiments

Spatial Volume	Time Scale			
	Nanosecond	Microsecond	Millisecond	Quasi-Steady
Capsule	NIF/Omega	Z / Shock Tube	Flibe Cond.	—
Hohlraum/Convertors	HCX/HI Acc			—
Beam Paths	HCX/HI Acc			Flibe Cond.
Pocket Void/Vent Paths	—			—
Condensing Region	—	Shock Tube		—
Pocket Liquid	Shielding	Liq. Relax.	Water Loop	—
Magnets/ Shielding		—	—	Mech./Activ.
Chamber Structures		—	—	Chem./Mech./ Activ./Safety
Coolant Recirc./Heat Recovery/Chemistry	—	—	—	Flibe Chem./Safety
Accelerator	HCX/HI Acc	—	—	—
Target Injection	—	—	Gas Gun	—
Target Fabrication	—	—	—	Target Fab.

Phenomena scaling boundaries

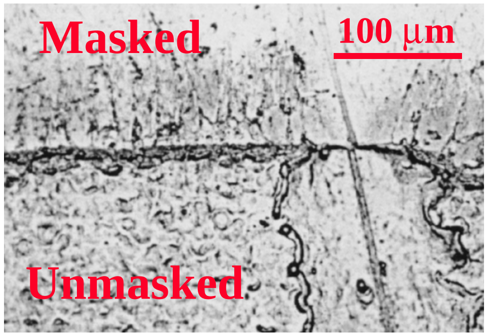
Large-scale exp. facility w/ industrial process dev.

Bench-scale to room-scale experiments

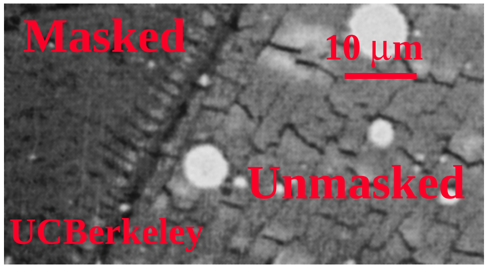
*(Liquid-protected chamber example, dry wall is similar)

X-ray ablation is an example of an IFE microsecond phenomena

- **Approximately 25% of IFE indirect-drive fusion yield is released as soft x rays**
  - **provides important source of debris, impulse loading**
  - **fluences range from ~3 to 1000 J/cm^2 for various chamber designs**
  - **simplification (relative to most laser ablation) comes from**
    - » **1-D hydrodynamics due to large areas**
    - » **simple interactions of x-ray photons with matter**
  - **complexity comes from**
    - » **material equation of state**
    - » **energy transport during ablation**
- **Related research**
  - **laser ablation**
    - » **many applications….**
  - **x-ray lithography**



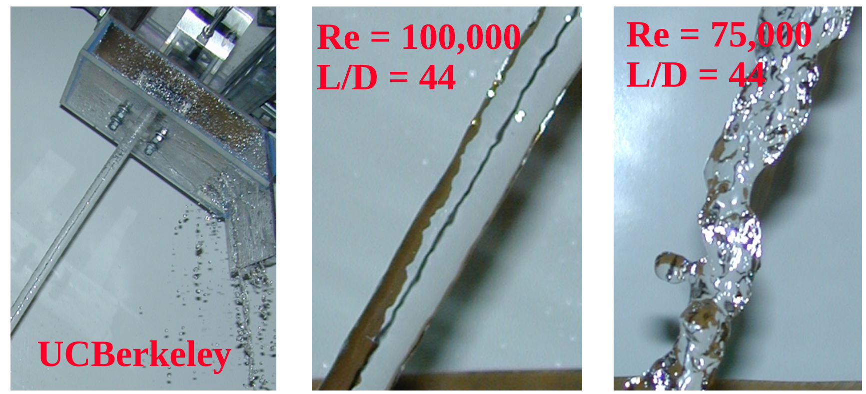
X-ray ablation of aluminum (3.3 J/cm^2)



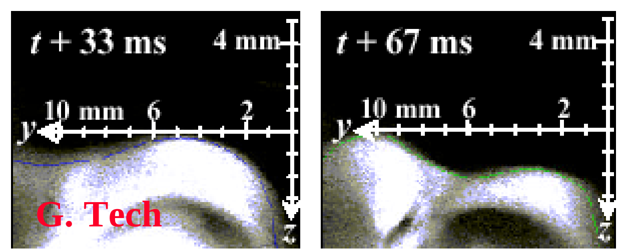
X-ray ablation of alumina (2.5 J/cm^2)

Liquid jet dynamics is an example of a millisecond IFE phenomena

- **Superimposing liquids between targets and structures requires detailed understanding of jet hydrodynamics and interactions**
  - **a molten salt—Li_2BeF_4—is most interesting due to negligible waste generation and extremely low tritium solubility**
  - **scaled water experiments accurately replicate hydrodynamic (not heat transfer) phenomena**
  - **complexity comes from**
    - » **very low nozzle contraction ratios**
    - » **disruption phenomena in vacuum**
- **Related research**
  - **Liquid jet generation/dynamics**
    - » **e.g. fuel injection; cutting**
  - **Dispersed media response to impulse loading**
    - » **wave propagation in two-phase flow**
    - » **shock propagation in porous solids**
    - » **material collision dynamics**



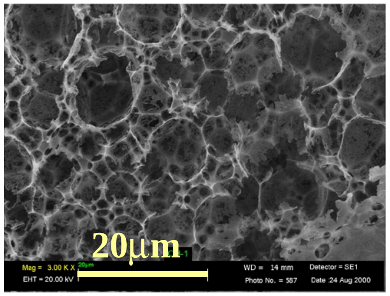
low-contraction nozzle | w/ conditioning | w/o conditioning



LIDF measurement of jet surface topology

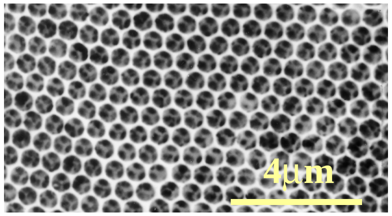
Low-density metal foam formation is an example of a quasi-steady IFE phenomena

- **HIF targets provide reproducible, controllable HI energy deposition by using low-density stopping materials (metal foams) to minimize hydrodynamic motion**
  - **optimal densities: 0.03 to 1.0 g/cc Au ; 0.07 g/cc Fe; 0.06 g/cc Al**
  - **LANL has created extremely low density plastic foams (for direct-drive targets)**
  - **Materials science issues for metal foams**
    - » **Nanofabrication and templating**
    - » **Chemistry (extremely high specific surface area)**
    - » **Densities to be reduced by factor of several from state of art in other applications (e.g. U. Del.)**



10 mg/cc CH foam (LANL)

- **Related research**
  - **Catalysts**
  - **Super insulation**
  - **Optoelectronic devices**
  - **Advanced coatings**



3 g/cc Au foam for opto-electronics (U. Delaware)

Conclusions

- **Phenomena in inertial fusion systems span an extraordinary range of scales**
  - **The decoupling of IFE phenomena in time and space provides scaling insights that can improve modeling of other complex systems**
- **The phenomena of interest for IFE are characterized by extreme values of one or more parameters**
  - **Studying these extremes provides fundamental insights**
- **A coherent approach exists for identifying and designing IFE experiments to minimize scaling distortion**
  - **All microsecond, millisecond and quasi-steady phenomena experiments envisioned in the next decade can be done at bench or room scale**

> **The most interesting research is to be found at the extremes.**
> C.L. Tien, University Professor, U.C. Berkeley