



INTEGRATED PLAN FOR MATERIALS R&D IN LASER INERTIAL FUSION ENERGY (IFE)

L. Snead (ORNL), N.M. Ghoniem (UCLA), J. Sethian (NRL)

Naval Research Laboratory (NRL)

Washington, D.C.

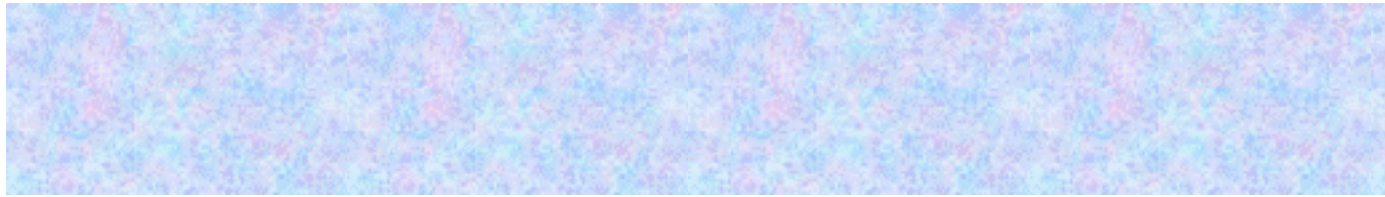
May 31- June 1, 2001





- **Statement of Objectives;**
- **Key Science and Technology Challenges;**
- **Framework and Integration Logic;**
 - ❑ **Approach;**
 - ❑ **On-going Activities;**





➤ Development of Material Systems and Components for High Average Power Density Laser Optics;

- ❑ Develop both reflective and transmissive optics;
- ❑ Investigate effects of laser, X-ray, neutron and ion/debris;
- ❑ Critical issue for transmissive optics : degradation of transmissivity as a result of color center formation;
- ❑ Considered materials : SiO_2 , CaF_2 , MgF_2 and Al_2O_3 ;





- ❑ **Critical issue for reflective optics: degradation of the Laser-Induced Damage Threshold (LIDT) by surface deformation mechanisms;**

- ❑ **Considered material systems: FCC metals (e.g. Cu & Al), BCC metals (e.g. Mo & W), SiC, Layered structures and innovative design concepts ;**

- ❑ **Design objective:**
 - **Minimize (or compensate for) gross structural deformation by gravity, thermal and mechanical loads;**
 - **Control microscopic surface deformation caused by material defects.**

➤ Development of Reliable Chamber Structures and Components for the IFE Dry-wall Concept;

❑ Key Issues:

- Pulsed neutron damage;
- Intense X-ray effects;
- Effects of repetitive thermomechanical shock Loading.

- ❑ Material Systems : engineered high-temperature composites, with variants of C/C, C/SiC, SiC/SiC; (2) Refractory alloys (W & Mo); ODS Ferritics; Layered structures.

(1) Pulsed Neutron Effects on Material Degradation:

- ❑ Key Issue: Effects of damage rate (6-7 orders of magnitude larger than MFE) and inter-pulse transients on microstructure & properties.
- ❑ Common Issues with MFE:
 - ❖ High rates of gas generation in C/ SiC;
 - ❖ Burnup and stoichiometric changes;
 - ❖ SiC: Degradation of K_{th} , micro-cracking, differential swelling, hermiticity.
 - ❖ C: Dimensional stability (i.e. shrinkage/ swelling);
- ❑ Questions: (1) property extrapolation; (2) materials engineering; (3) effects of pulsed irradiation & excessive gas generation.

(2) Pulsed X-Ray Effects on Surface Ablation:

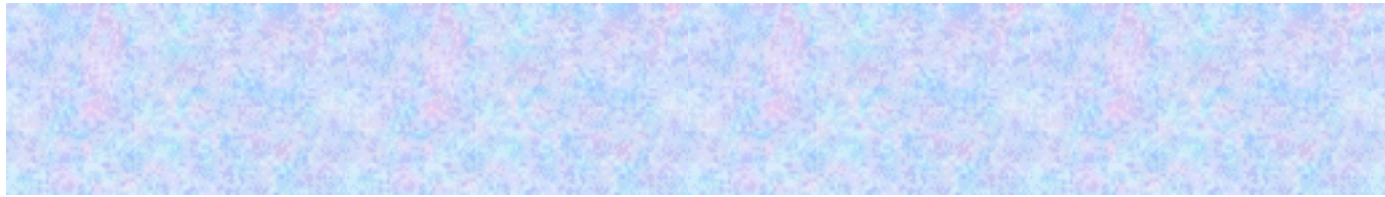
- ❑ Mechanisms of Radiation Enhanced Sublimation (RES) in intense non-equilibrium conditions;
- ❑ Surface modification technologies for materials engineering;
- ❑ Photon-surface interaction processes:
 - ❖ Threshold events;
 - ❖ Effects of surface defects, segregation & contamination;
- ❑ Cumulative X-ray pulsing effects on sub-threshold events;
- ❑ Effects on degradation of optics.

(3) Synergistic Neutron & Thermomechanical Damage to Structural Components;

- ❑ Transient pressure and surface loading effects:
 - ❖ Stress waves, vibrations;
 - ❖ Gradual destruction of fiber/ matrix/ interphase properties.
- ❑ Degradation of strength by neutrons/ thermo-mechanical loads;
- ❑ Realistic lifetime and reliability limits, which account for damage evolution mechanisms;
- ❑ Integration of component design is necessary.

(4) Control of Macroscopic and Microscopic Surface Deformation of Reflective Optics:

- ❑ Multiple length-scale deformation by: differential swelling, thermal expansion, gravitational & mechanical loads, sub-surface defects & fatigue-induced dislocation motion;
- ❑ Macroscopic deformation: >> control via deformable mirrors and active control loops;
- ❑ Microscopic deformation: >> control via materials design, layered structures and coatings.
- ❑ Issues:
 - ❖ Length-scale limit for active deformation control ?
 - ❖ Function separation into optics & mechanical?



(5) Mechanisms of Laser-Induced Damage in Reflective Optics:

- ❑ LIDT is caused by surface and near-surface defect generation. For a single-shot $\sim 1\text{-}10\text{ J/cm}^2$.
- ❑ Amorphous & engineered coatings can improve LIDT for single shot (amorphous Ni $\gg 40\text{ J/cm}^2$).
- ❑ Data and models on multiple-shot LIDT are lacking. Limited data shows a factor-of-ten reduction after 10000 shots.
- ❑ Role of microstructure engineering (e.g. coatings, surface modification techniques & nano-structured multi-layers)?
- ❑ Effects of dust, debris and neutrons?



(6) Mechanisms of Optical Absorption in Transmissive Optics:

- ❑ Mechanisms of oxygen-deficient centers (F-centers), strained Si-O bond centers, E⁺ centers and non-bridging hole centers have been determined.
- ❑ Fluence limits for concentration buildup of color centers?
- ❑ Annealing kinetics, agglomeration & interaction with H, T, and He?
- ❑ Transmutation effects? Latkowski calculates 27.5 appm/FPY H, 69.1 He, 54 C, 2 N, 15 Mg, and 4 Al.
- ❑ Transient effects: in-situe versus ex-reactor behavior?



(7) Safety and Environmental Impact of Materials:

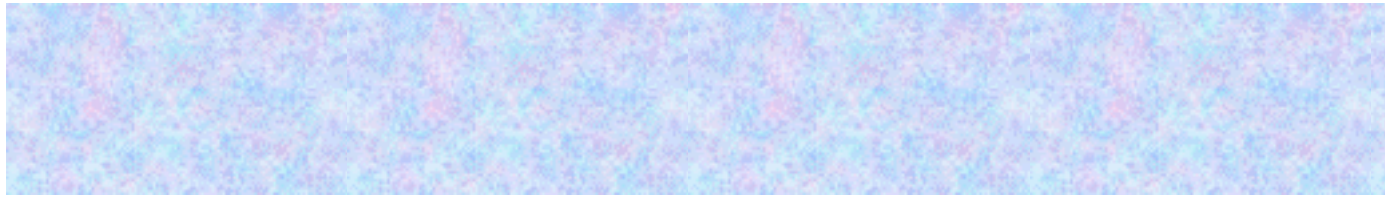
- The interaction of tritium with ceramic fiber composites (graphite and SiC) and refractories ?
- The attachment, release and diffusion of hydrogen isotopes in graphite and SiC?
- Safety and environmental limits on alloy compositions can be leveraged from MFE studies.





- ❑ “Cradle-to-Grave” approach;
- ❑ Balanced Mix between:
 - Fundamental understanding of mechanisms;
 - Integration of material and design concepts;
 - Data-base generation for IRE and ETF.
- ❑ Experiments:
 - ❖ Collection of a database;
 - ❖ Motivated by theoretical ideas and concepts;
- ❑ Theory & Modeling:
 - ❖ Validated by experiments within the program;
 - ❖ Advanced models of structural performance and reliability.





❑ X-Ray Ablation Experiments and Analysis of Optics (LLNL):

- ❑ IFE-relevant x-ray fluences may be as low as 10 mJ/cm^2 (below the single-shot ablation threshold)
- ❑ The repetitive nature of the insult experienced by the final optic ($>10^8$ shots) is to be investigated;
- ❑ Falcon Laser & Z-pinches ($5\text{-}100 \text{ mJ/cm}^2$ x-ray pulses in a few nsec) will be used for $10^4\text{-}10^5$ shots;
- ❑ A physical model of rapid surface heating and electronic excitation of surface states, followed by ejection of ions will be developed.





❑ Final Optics Material Development (LLNL):

- ❑ Annular Core Research Reactor (ACRR) at SNL will be used;
- ❑ Extremely pure materials (CaF_2) will be used to study the effects of impurities;
- ❑ Existing SiO_2 samples with ~5 year IFE-equivalent doses (irradiated at LANSCE in 1995) will also be tested ;
- ❑ Additional materials (e.g. MgF_2 and Al_2O_3 & reflective optics?) will also be tested.
- ❑ Thermal annealing studies to determine kinetics.

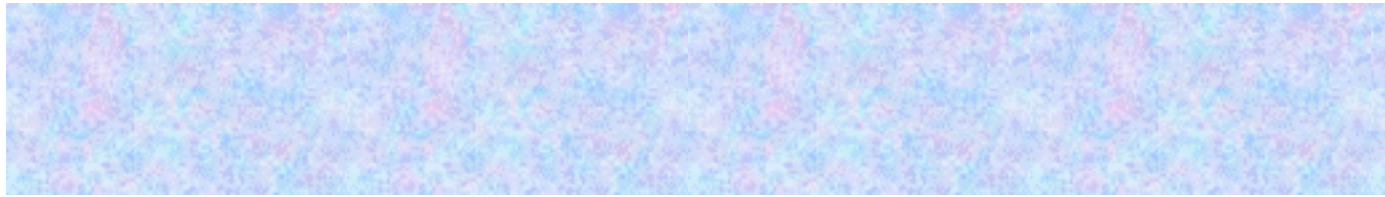




❑ MD Damage Simulations in Optical Materials (LLNL):

- ❑ Large-scale MD simulations of fused silica will be used to characterize the recoil-induced damage in terms of density, coordination, ring statistics and correlation.
- ❑ Model will be related to the extensive experimental data available for fused silica ?
- ❑ Research will be useful in the future to predict the response of candidate materials for the final optic.





❑ MD Damage Simulations in Chamber Materials (LLNL):

- ❑ Study defect production and migration in C & SiC (?)
- ❑ Construct a global model of defect production and accumulation.
- ❑ Compare results (?) with those for continuous irradiation and experimental measurements.





❑ Pulsed Fusion Neutron Source Development (U. Texas):

- ❑ Measure the fusion yield from exploding clusters with 10 J laser pulses using the JanUSP laser at LLNL;**
- ❑ Explore the yield per shot as function of laser pulse width, and the yield increase as the clusters are made larger;**
- ❑ How will these experiments be correlated with MD studies?**





❑ IFE Final Optics Neutron Irradiation (LANL):

- ❑ Using LANSE and WNR, radiation effects on SiO_2 , CaF_2 transmissive optics will be investigated.
- ❑ Pre- and post-irradiation examination of irradiated samples will be carried out.
- ❑ Point defect models, to determine the concentration of color centers in irradiated samples will be correlated to measurements.





- ❑ Laser Induced Damage Threshold (LDIT) of GIMM (UCSD):**
 - ❑ The goal is to experimentally determine LIDT at grazing incidence with clean surfaces;**
 - ❑ The reflectivity and wave front changes of clean surfaces will also be modeled;**
 - ❑ The effects of surface contaminants on reflectivity, LIDT and wave front will be measured and modeled.**





Conclusions



- ❑ **Very challenging scientific and technical issues for IFE materials require a dedicated, self-consistent and integrated R&D approach.**
- ❑ **Augmentation and focusing of on-going activities are recommended;**
- ❑ **A detailed R&D plan has been worked-out, with ample opportunity for modifications and improvements.**

