MCNP Fusion Modeling of Electron-Screened Ions

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MCNP Modeling of Lattice Confinement Fusion (LCF)

- Introduction
- Current MCNP Fusion Modeling Capabilities
- LCF Related Modeling Accomplished with MCNP
- LCF Calculations After MCNP Modeling
- Nuclear Reaction Modeling Limitations
- Proposed MCNP Enhancements
- Summary
• NASA GRC and DoE LBNL discovered novel means of driving nuclear fusion reactions in deuterated lattices, **Lattice Confinement Fusion (LCF)**

• Lattices provide Coulomb Barrier reduction through lattice, plasma, conduction and shell electron screening

• Weak and strong (degenerate) electron screening increase the fusion rate

• Lattice fusion rates increase by orders of magnitude over bare nuclei fusion

• NASA GRC used MCNP to guide electron screened, deuterated lattice, nuclear fusion research
  - Model γ irradiated deuterated metals, activation, fission and shielding (MCNP-6.1 with Vised)
  - Model detector responses (MCNPX-PoliMi

• However, neither NASA nor LBNL were able to model LCF nuclear reactions with MCNP (or GEANT-4).
Current MCNP Fusion Modeling Capabilities

• MCNP6.2 Overview: Electron screening for fast ions, only > 100 keV ion support

• MCNP6-McDeLicious: 40 MeV accelerated deuteron, $^6$Li(d,n) neutron source

• ITER Tokamak Models: Only neutron propagation and interaction
  • Using MCNP for Fusion Neutronics, Dissertation by Frej Wasastjerna at Helsinki University of Technology, (Dec 2008).
  • Integration of the Full Tokamak Reference Model with the Complex Model for ITER Neutronic Analysis, J. Yang, et. al., (ORNL), Fusion Science and Technology, (Nov 2018).

• Laser Inertial Fusion-Fission Model: Hybrid Fusion neutron source for a Fission Reactor

• Nuclear Fusion Data Modeling: NJOY data conversion of ENDF, FENDL for MCNP neutron transport/activation
LCF Related Modeling Accomplished in MCNP

• Model 1 eV - 15 MeV photons and 10 eV- 15 MeV electrons
  • Bremsstrahlung photo-neutron triggered Lattice Confinement Fusion

• Model thermal, epithermal and fast neutrons
  • LCF lattice activation and momentum transfer for reaction gain
  • LCF neutron scattering and capture
  • LCF fast neutron momentum transfer (recoil)

• Model actinide fission
  • Synthetic HPGe detector

• Model neutron spectrometer response functions
  • Scintillator response functions with CVT PoliMi under MCNPX
  • U2D using moderated planes of $^6$Li neutron capture electronics\(^1\)

  • Only track $> 100$ keV charged fusion products
  • Only model $\geq 1$ MeV charged fusion products

Dynamitron 2.9 MeV Bremsstrahlung with triggered ErD$_3$, DD fusion with boosted energy neutrons.

**Pulse Shape Discrimination (PSD) to Remove $\gamma$ & Unfold Neutron Spectra**

Detector Counts: Fueled & Unfueled

**Neutron Spectra, Net: Fueled minus Unfueled**

- TS1576 ErD$_3$ and TS589 Er-unfueled
- TS1576 (Er/D$_3$, EJ-309 (HV))

Note: Unfolding uncertainty bars 2-sigma.

**LCF Calculations After MCNP Modeling**

Nuclear Reaction Modeling Limitations
MCNP, GEANT-4 and SRIM/TRIM

MCNP Particle Interaction Modeling Domains

- **No model for DD, DT and D³He fusion reactions at peak cross-sections < 1 MeV.**
  - LCF gain is from large-angle scattering of electron screened fusion alpha, proton and neutron products causing deuteron recoils

- **No model for electron screened ions < 10 keV.**
  - Applicable as ions slow

- **SRIM/TRIM models ion scattering**
  - But not nuclear reactions

- **No model for electron screened deuteron stripping reactions**
  - Possible source of fast neutrons: $^A\text{M}_Z(d,n)^{A+1}\text{M}_{Z+1} n_{KE} >> 4$ MeV

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1. **MCNP6 Class**, H. Grady III and James, Michael R., LANL, LA-UR-14-21281 (2014)
Proposed MCNP Enhancements

- Incorporate Frascati fusion neutron generator subroutines (10—50 keV deuterons) for ITER (International Thermonuclear Experimental Reactor).

- Test with NASA bremsstrahlung photoneutron-deuteron recoil 64 keV average (32 keV center-of-mass) kinetic energy.

- Add LCF Theory Paper enhancement factor, $f(E)$, for electron screening < 10 keV deuteron kinetic energy.

- Test with LBNL plasma/glow discharge 1.25 keV - 6 keV center-of-mass deuteron kinetic energy.

- Add DFT (Density Functional Theory) and DMFT (Dynamic/ Density Mean Field Theory) < 1 keV electron screening calculations to modify Gamow and Astrophysical factors.
• Augment MCNP to model nuclear reactions
  • Add ion scattering from 10 keV – 64+ keV
  • Add electron screening of ions from < 1 keV - 10 keV
• NASA and DoE would benefit from this modeling
  • Terrestrial and space-based fusion reactor technology
  • Astrophysics of warm dense matter (Jovian-like planets), stellar nucleosynthesis
  • Differentiate between boosted fusion and stripped neutrons
• NASA is interested in partnering with LANL MCNP developers to fully incorporate these enhancements into MCNP.
• Consistent with NASA/DoE MOU on Space Nuclear Power
References from MCNP Enhancements

• Incorporate Frascati fusion neutron generator subroutine supporting ITER (International Thermonuclear Experimental Reactor):
  • D-D, D-T and D-³He fusion from 10 keV - 50 keV
  • Charged particle scattering using SRIM/TRIM tables (10 keV – 100 keV)
• Test with NASA bremsstrahlung 64 keV average photoneutron-deuteron recoil KE (32 keV center-of-mass)
• Add LCF Theory Paper enhancement factor, f(E), for electron screening < 10 keV deuteron kinetic energy.
• Test with LBNL plasma/glow discharge, 1.25 keV - 6 keV center-of-mass deuteron kinetic energy.
• Add DFT (Density Functional Theory) and DMFT (Dynamic Density Functional Theory) < 1 keV electron screening calculations to modify Gamow and Astrophysical factors.