MCNP Fusion Modeling of Electron-Screened Ions

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Theresa L. Benyo, Ph.D., NASA Glenn Research Center (GRC)
Lawrence P. Forsley, Global Energy Corporation
MCNP Modeling of Lattice Confinement Fusion (LCF)

NASA Glenn Research Center (GRC)
Advanced Energy Conversion Project

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• LCF Calculations After MCNP Modeling
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**Introduction**

- 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 detector responses (MCNPX-PoliMi)
  - Model γ irradiated deuterated metals, activation, fission and shielding (MCNP-6.1 with Vised)
- 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, $^6,^7\text{Li}(d,n)$ neutron source

- **ITER Tokamak Models:** Only neutron propagation and interaction
  - Using MCNP for Fusion Neutronics, Dissertation by Frej Wasastjerna at Helsinski University of Technology, (Dec 2008).

- **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 \( ^{6} \text{Li} \) neutron capture electronics\(^1 \)
  - Only track > 100 keV charged fusion products
  - Only model ≥ 1 MeV charged fusion products

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

**Note:** Unfolding uncertainty bars 2-sigma.

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

- **TS1576 ErD$_3$ net fluence 2.9 MeV (EJ309)**
- **2.2-2.45 MeV**
- **3.9-4 MeV**
- **5 MeV**
- **Boosted neutrons**

**Detector Counts: Fueled & Unfueled**

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

MCNP Particle Interaction Modeling Domains

- No model for DD, DT and \(D^3\)He fusion reactions at peak cross-sections < 100 keV.
  - 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\(^4\) models ion scattering
  - But not nuclear reactions
- No model for electron screened deuteron stripping reactions
  - Possible source of fast neutrons: \(^A\)\(M_2\)\((d,n)^{A+1}M_{Z+1}\) \(n_{KE} \gg 4\) 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 Exp. 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 Functional Theory) < 1 keV electron screening calculations to modify Gamow and Astrophysical factors.
Summary

• 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
Incorporate Frascati fusion neutron generator subroutine supporting ITER (International Thermonuclear Experimental Reactor):

- D-D, D-T and D-\(^3\)He 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.