Electromagnetic Dissociation Cross Sections for High LET Fragments

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2:15 - 2:30 pm (15 mins.)
OUTLINE

1. INTRODUCTION

2. ELECTROMAGNETIC DISSOCIATION (EMD)

3. RESULTS

4. CONCLUSIONS
Galactic cosmic rays (GCR) & solar particle events (SPE) are radiation hazards in space for humans & electronic components
- GCR contain all nuclei in periodic table
- Energies hundreds of GeV/nucleon (n) & beyond

Focus on GCR interactions
- Nuclei broken into lighter fragments upon interaction with target nuclei

Target nuclei represent nuclei making up
- Spacecraft shielding, human body, electronic components, etc.
- Example: $^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + n + \text{Al}$
**Introduction: Strong vs. Electromagnetic (EM)**

\[ ^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + \text{n} + \text{Al} \]

Short range strong interaction when projectile & target nuclei overlap.
**Introduction: Strong vs. Electromagnetic (EM)**

\[ ^{56}\text{Fe} + ^{27}\text{Al} \rightarrow ^{55}\text{Fe} + n + ^{27}\text{Al} \]

- **Short range strong interaction** when projectile & target nuclei overlap.
- **Long range EM interaction** when projectile & target nuclei miss each other.
Electromagnetic Dissociation

\[ \sigma_{\text{EMD}} = \int dE_\gamma N(E_\gamma) \sigma(E_\gamma) \]

Photonuclear cross section \( \sigma(E_\gamma) \) shown by red curve, plotted against photon energy \( E_\gamma \).

Green & blue curves show virtual photon spectra \( N(E_\gamma) \) for low & high energy projectiles.

Previously, EMD models (e.g. within NUCFRG3) calculate single proton (p) production, single neutron (n) or light ion production.
- Light ion $\equiv$ isotope of hydrogen (H) or helium (He)
- Deuteron ($d \equiv ^2H$), triton ($t \equiv ^3H$), helion ($h \equiv ^3He$), alpha ($\alpha \equiv ^4He$)

New model EMDFRG accounts for multiple nucleon production:
- 2p, 2n, 1p1n, 2p1n, 3p1$\alpha$, 2p2t, ... (in addition to single light ions)

Such processes important:
- Consider reaction $^{56}\text{Fe} + \text{Al} \rightarrow ^{52}\text{Cr} + X + \text{Al}$  high LET $^{52}\text{Cr}$
- Most probable EMD particles representing $X$ are 2p2n or $^4\text{He}$
- $^{56}\text{Fe} + \text{Al} \rightarrow ^{52}\text{Cr} + ^4\text{He} + \text{Al}$  EMDFRG & NUCFRG3
  $\rightarrow ^{52}\text{Cr} + 2p2n + \text{Al}$  EMDFRG
- $\sigma(^{52}\text{Cr}) = \sigma(2p2n) + \sigma(^4\text{He})$
- Production of high LET $^{52}\text{Cr}$, must include both multiple nucleon production of 2p2n plus light ion production of $^4\text{He}$
RESULTS

Compare:

- EMDFRG ———– with photonuclear parameterization for $\sigma(E_\gamma)$
- EMDFRG - - - - - - with photonuclear data for $\sigma(E_\gamma)$
- NUCFRG2 - - - - -
- NUCFRG3 .........

Focus on  EMDFRG ———–  and  NUCFRG3 .........
Excellent agreement for EMDFRG —— Poor agreement for NUCFRG3

Results - Single Nucleon

Excellent agreement for EMDFRG —— Worse agreement for NUCFRG3

2100 MeV/n: $^{16}\text{O} + \text{Target} \rightarrow ^{15}\text{N}$ (1p)

13.7 GeV/n: $^{28}\text{Si} + \text{Target} \rightarrow ^{27}\text{Al} + 1p$

2100 MeV/n: $^{16}\text{O} + \text{Target} \rightarrow ^{15}\text{O}$ (1n)

13.7 GeV/n: $^{28}\text{Si} + \text{Target} \rightarrow ^{27}\text{Si} + 1n$
RESULTS - SINGLE NUCLEON

Similar agreement for EMDFRG ——- and NUCFRG3 • • • • •
RESULTS - SINGLE NUCLEON

EMDFRG —- DATA - - - NUCFRG2 - - - - NUCFRG3 ● ● ● ●

Good agreement for EMDFRG ——– Poor agreement for NUCFRG3 ● ● ● ●
RESULTS - SINGLE NUCLEON

EMDFRG — DATA —- NUCFRG2 —- — NUCFRG3

Similar agreement for EMDFRG —— and NUCFRG3 • • • •

1000 MeV/n: $^{197}$Au + Target $\rightarrow ^{196}$Au (1n)

1260 MeV/n: $^{197}$Au + Target $\rightarrow ^{196}$Au (1n)

1700 MeV/n: $^{197}$Au + Target $\rightarrow ^{196}$Au (1n)

2100 MeV/n: $^{197}$Au + Target $\rightarrow ^{196}$Au (1n)
Excellent agreement for EMDFRG
Large Hadron Collider (LHC)

4,056.44 TeV/n: $^{208}$Pb + Target $\rightarrow$ 1n

Excellent agreement for EMDFRG
RESULTS - DOUBLE NUCLEON

EMDFRG —— DATA ——

Good agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]
**RESULTS - DOUBLE NUCLEON**

- EMDFRG —— DATA - - - MMM

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**Excellent agreement for EMDFRG ——**

\[ \sigma_{\text{NUCFRG3}} = 0 \]

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**Poor agreement for EMDFRG ——** (fit = - - -)

\[ \sigma_{\text{NUCFRG3}} = 0 \]
**Results - Double Nucleon**

- **EMDFRG**
- **Data**

### 1260 MeV/n: $^{59}$Co + Target → $^{57}$Co (2n)

- $\sigma$ (mb) vs. Z target
- Good agreement for EMDFRG

### 1700 MeV/n: $^{59}$Co + Target → $^{57}$Co (2n)

- $\sigma$ (mb) vs. Z target

### 2100 MeV/n: $^{59}$Co + Target → $^{57}$Co (2n)

- $\sigma$ (mb) vs. Z target

### 1000 MeV/n: $^{197}$Au + Target → $^{195}$Au (2n)

- $\sigma$ (mb) vs. Z target

$\sigma_{\text{NUCFRG3}} = 0$
RESULTS - DOUBLE NUCLEON

EMDFRG —— DATA ——-

Reasonable agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]
RESULTS - TRIPLE NUCLEON

Excellent agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]

Poor agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]
RESULTS - TRIPLE NUCLEON

Mixed agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]
RESULTS - MANY NUCLEON

Good agreement for EMDFRG ——– $\sigma_{NUCFRG3} = 0$

Poor agreement for EMDFRG ——– (fit = - - -) $\sigma_{NUCFRG3} = 0$
Excellent agreement for EMDFRG — Poor agreement for NUCFRG3
Excellent agreement for EMDFRG ——– $\sigma_{\text{NUCFRG3}} = 0$
CONCLUSIONS

- New EMDFRG model for single & multiple nucleon & light ion

- Calculations are compared to complete set of experimental data

- Agreement with data is excellent for all cases relevant for space radiation

- Single, double & triple nucleon removal data agrees very well over the whole range of energies, projectiles and targets

- Alpha production data agrees very well for $^{28}\text{Si}$ projectiles, including alpha production in coincidence with single nucleons

- Some discrepancies, but not important for space radiation, because cross sections are quite small
  - Exception is for double nucleon removal from $^{28}\text{Si}$
THE END

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