

NUCFRG3:

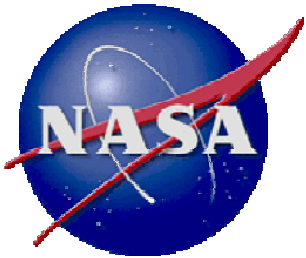
Light ion improvements to the nuclear fragmentation model

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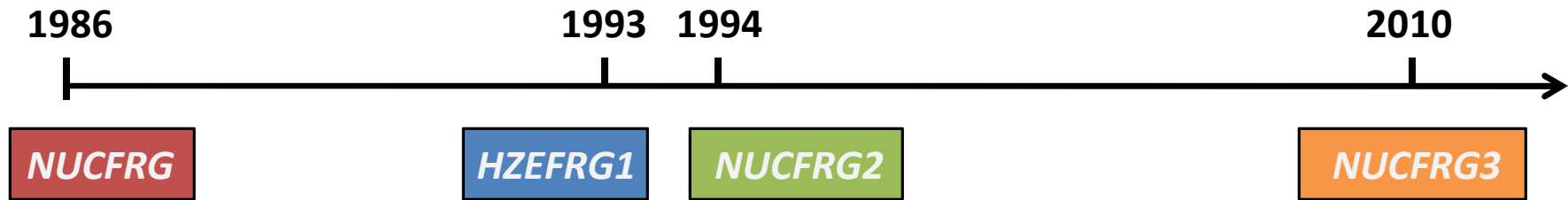
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Introduction

Development of the NUCFRG series of nuclear fragmentation model began at NASA Langley Research Center in the mid-1980's in order to provide a fast, accurate, and reliable algorithm for generating nuclear fragmentation cross section databases for galactic cosmic ray (GCR) transport and shielding studies relevant to future NASA missions.



Applications

- Space-related assessments and applications are partially dependent on light ion nuclear reactions and light ion production in the GCR spectrum.
- NUCFRG2 provides the nuclear fragmentation cross sections for some versions of the deterministic particle transport code **HZETRN** (High charge (Z) and Energy TRaNsport).
- NUCFRG2 cross sections are used in the event generator of the Monte Carlo radiation transport code **HETC-HEDS** (High Energy Transport Code – Human Exploration and Development of Space).
- The abrasion–ablation and electromagnetic dissociation (EMD) models, on which NUCFRG2 is based, has been incorporated into **Geant4** (GEometry ANd Tracking).
- The continued development of an accurate high-energy heavy-ion cross section model is necessary to obtain reliable space radiation shielding and health risk assessments when using space radiation transport codes.

Light Ion Improvements

- Light ion production mechanisms include, but are not limited to:
 - Nuclear Abrasion
 - Nuclear Ablation
 - ✓ **Coalescence**
 - ✓ **Electromagnetic Dissociation (EMD)**
- **Coalescence** is a production mechanism for light ions, in which nucleons that are spatially and energetically similar will be coalesced into light ions by the strong nuclear force.
- In an **EMD** reaction, a projectile nucleus is excited by the absorption of a virtual photon, which is supplied by the target nucleus. The projectile subsequently decays by the emission of nucleons or light ions.
- Physics-based improvements have been incorporated into an updated version of the nuclear fragmentation code, NUCFRG3, which include the replacement of the simple light ion production model with the coalescence model and improved EMD cross sections.

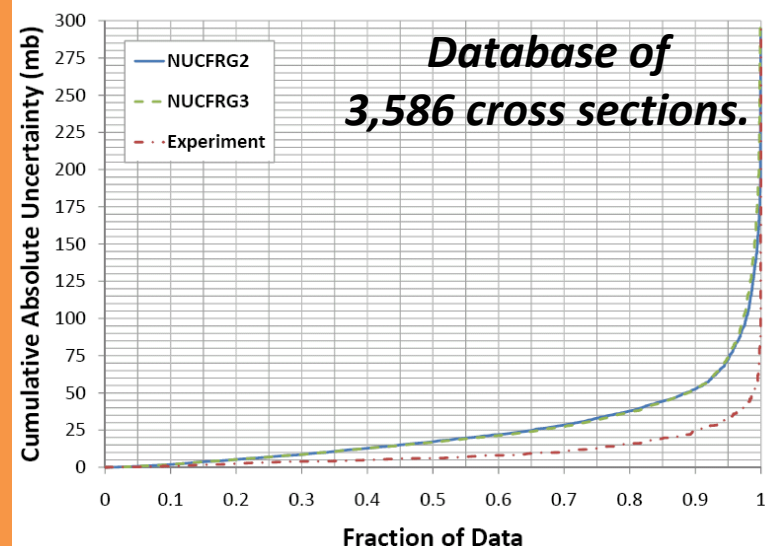
Model Evaluation and Validation

- In order to determine whether the updates to NUCFRG2 have provided model improvements, the changes to the predictive capability must be assessed.
- The four major components to predictive capability include:
 1. **Physics Modeling Fidelity**
 - ✓ **Code Verification**
 - ✓ **Solution Verification**
 4. **Model Validation / Uncertainty Quantification**
- The two parts to **Model Validation / Uncertainty Quantification** that are of particular concern for assessment of predictive capability include:
 - I. Uncertainty of models as determined by ***comparisons to the relevant available data.***
 - II. The ***applicability of the validation database*** to the application on interest.
- It is important to remember that for a given validation database, the model with less estimated uncertainty is obviously preferred. The quality and quantity of the data fundamentally limits the degree to which prediction uncertainty can be quantified.

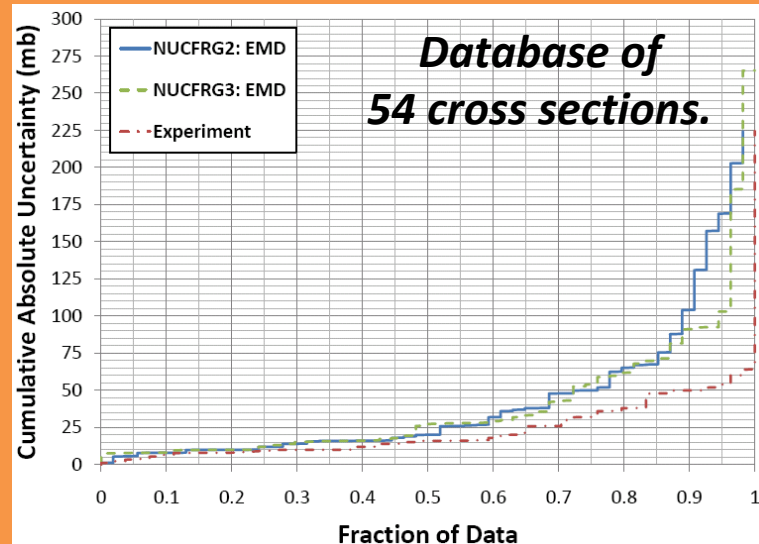
Results

- To assess the global accuracy of NUCFRG2 and NUCFRG3, the models are compared to available experimental data in the assembled database using the **cumulative uncertainty distribution**.
- All databases are only sparsely populated.

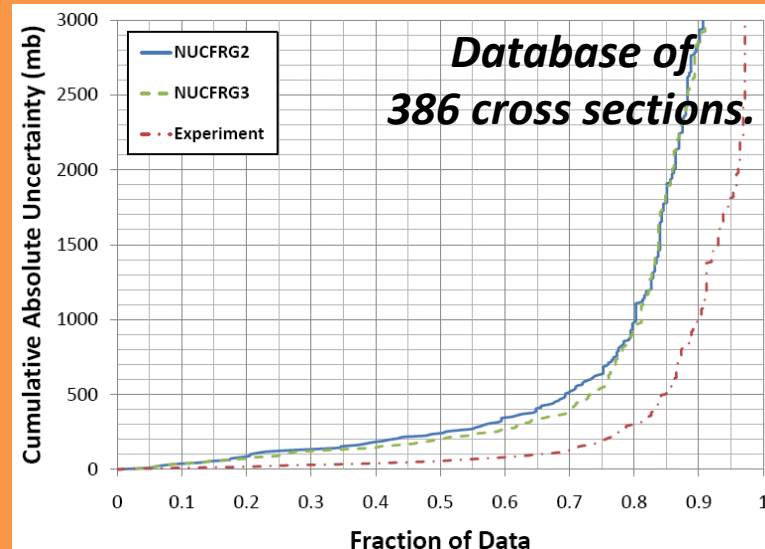
Heavy Ion Validation



EMD Validation



Light Ion Validation



Results: Light Ion

- To quantify the uncertainty of the NUCFRG models compared to sparse experimental data, the **median uncertainty metric** was utilized.
- The light ion database consists of **386 cross sections** and sparsely populates the phase space of interest.

Energy (MeV/n)	Median Uncertainty (mb)	
	NUCFRG2	NUCFRG3
0 - 300	767	721
300 - 1000	342	287
> 1000	174	110

Fragment Charge (Z)	Median Uncertainty (mb)	
	NUCFRG2	NUCFRG3
1	454	352
2	158	158

Target	Median Uncertainty (mb)	
	NUCFRG2	NUCFRG3
H	40	40
Be	125	119
C	118	98
Ne	106	49
Al	235	156
Ar	1141	1029
Ni	1034	1033
Cu	268	214
Nb	118	144
Ag	328	200
Sn	386	423
Au	3583	3097
Pb	543	548

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Results: Light Ion

- To quantify the difference between the **median** and the **uncertainty** of the **cross sections** and **cross sections of interest**.

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Results: Light Ion

- To quantify the difference between the **median** uncertainty and the experimental data,
- The light ion data are categorized by **sections** and sections of interest.

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Conclusions

- Radiation transport model calculations require an accurate and reliable database of relevant fragmentation cross sections.
- **The predictive capability of the NUCFRG code has been increased** by physics-based changes to the coalescence and EMD models.
- By comparing NUCFRG3 with heavy ion experimental data it was shown that the physics-based **coalescence and EMD model improvements have been implemented properly and are functioning as intended outside the phase space of interest.**
- **Inside the phase space of interest** for light ion production, the NUCFRG3 model did not lose predictive accuracy. This means that **the new numerical algorithmic updates have been executed properly.**
- **For light ion production**, it was observed that **NUCFRG3 has a smaller median uncertainty than NUCFRG2**, for most cases.