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# FREYA Developments 2015-2016

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**FREYA Developments 2015-2016**  
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Together with Jorgen Randrup (LBNL), we are developing the event-by-event fission Monte Carlo code, FREYA (Fission Reaction Event Yield Algorithm). We are part of an NA22 venture project, Correlated Data in Nuclear Fission, together with LANL, LBNL and University of Michigan Nuclear Engineering.

This year we finished updating FREYA with several new isotopes: neutron-induced fission of  $^{233}\text{U}$  and  $^{241}\text{Pu}$  as well as spontaneous fission of  $^{238}\text{Pu}$  and  $^{242}\text{Pu}$ . Approximations were used to allow for neutron-induced fission up to 20 MeV (including multi-chance fission and pre-equilibrium neutron emission).

We also improved the physics of photon emission in FREYA in the following ways: the continuum emission now proceeds through the giant dipole resonance; after statistical photon emission, the RIPL-3 library is used to emit photons according to discrete energies given in the table; if the isotope has no photon emission lines in the library, the emission is handled as before with transitions down the yrast line until the spin is exhausted.

The updated code was handed over to Jerome Verbeke and Chris Hagmann for adapting to the MCNP format and, after that process was complete, was subsequently handed over to MCNP developers at LANL. The revised code went through the process of review and release. The FREYA user manual has also been updated to include the new features and isotopes.

We have been studying the sensitivity of neutron observables to the FREYA input distributions. Patrick Talou generated 1000 different yield functions,  $Y(A,Z,TKE)$ , for  $^{252}\text{Cf}(sf)$  based on fits to available data on the yields as a function of fragment mass,  $Y(A)$ , and the total kinetic energy distribution as a function of heavy fragment mass,  $TKE(A_H)$ , and its width,  $\sigma_{TKE}(A_H)$ , to obtain  $Y(A,TKE)$ . These results are augmented by Wahl systematics to include the fragment charge. We have so far found that the neutron observables do not depend strongly on the yield functions. We also found that the yield functions, constrained by data, are not sufficient to constrain the average neutron multiplicity within the evaluated uncertainty. A paper on this is in progress.

We began working on a paper on photofission with the University of Michigan while on a Consortium for Verification Technology fellowship. This is an important paper because they have measured the neutron multiplicity distribution, the prompt fission neutron spectrum, and the energy correlation of two neutrons as a function of angle of separation for the first time in photofission of  $^{235}\text{U}$ . We have made FREYA calculations to compare with the data but the paper is still in progress since the student left and other researchers have had to take over the analysis. We expect to submit the paper in the next several months, after the analysis is complete.

Papers this year:

Prompt Fission Neutron Spectrum of Actinides, R. Capote et al, Nucl. Data Sheets 131 (2016) 1.  
R. Capote, D. Smith and I edited the paper for Nucl. Data Sheets.

Correlations of neutron multiplicity and gamma-ray multiplicity with fragment mass and total kinetic energy in spontaneous fission of  $^{252}\text{Cf}$ , Taofeng Wang et al, Phys. Rev. C 93 (2016) 014606.  
Jorgen Randrup and I made FREYA calculations to compare to the data given in the second paper.

Integration of the LLNL Fission Library/FREYA package into MCNP6, J.M. Verbeke, M.E. Rising, and R. Vogt, to be published in the proceedings of the American Nuclear Society Advances in Nuclear Nonproliferation Technology and Policy Conference (ANTPC), held in Santa Fe in September 2016.

Neutron-neutron and neutron-photon correlations with FREYA, R. Vogt and J. Randrup, to be

published in the proceedings of ND2016, held in Bruges, Belgium in September 2016. I presented a poster at the meeting.

Talks this year:

Monte Carlo Modeling of Fission, at the DNP meeting in September 2015. While a contributed talk, the abstract was invited for a mini-symposium on applications of nuclear physics.

Sensitivity Study of  $^{252}\text{Cf(sf)}$  Observables to FREYA Inputs, talk at the CSEWG/USNDP meeting, BNL, November 2015. (This same talk was given at our NA22 Venture Collaboration Meeting in Santa Fe in December 2015.)

The Fission Physics in FREYA and the Sensitivity of the Results to Physics Inputs, seminar at the University of Michigan, March 2016.

Neutron-neutron and neutron-photon correlations with FREYA, ND2016, held in Bruges, Belgium in September 2016. I gave a short talk to introduce my poster.

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