Status of the n+^{35}Cl Cross Sections

Marco T. Pigni
Nuclear Data and Criticality Safety
Oak Ridge National Laboratory, Oak Ridge, TN

Nuclear Data Advisory Group (NDAG) meeting
Brookhaven National Laboratory, November 4–8 2019, Upton, NY

Motivations

Reactor and Criticality Safety Applications

- New generation of nuclear reactor based on molten salt and designed to operate in a fast neutron spectrum
- Large amount of salt used to operate modern fast molten reactors drives the need to precisely know the chlorine cross sections
- The use of chlorine depleted in ^{35}Cl instead of natural abundance would result in substantial difference in cost estimates
- Newly developed reactors needs to satisfy enhanced requirements on nuclear criticality safety regulations
- Chlorine can be present in plutonium solutions, electrorefining processes, and salts processed in fuel cycle facilities

Reference Dosimetry Calculations

- Taking into account the concentration and the cross section, Kerma factor ($K = N \cdot \sigma$) are necessary to estimate the physical and biological dose delivered to the tumor and healthy tissue
- ^{35}Cl(n,p) contributes significantly to the neutron Kerma due to the resonances

Astrophysics

- ^{35}Cl involved in the production of ^{36}S
- ^{35}Cl/^{37}Cl deviates from solar isotopic ratio of elements heavier than CNO (Carbon, Nitrogen, Oxygen)

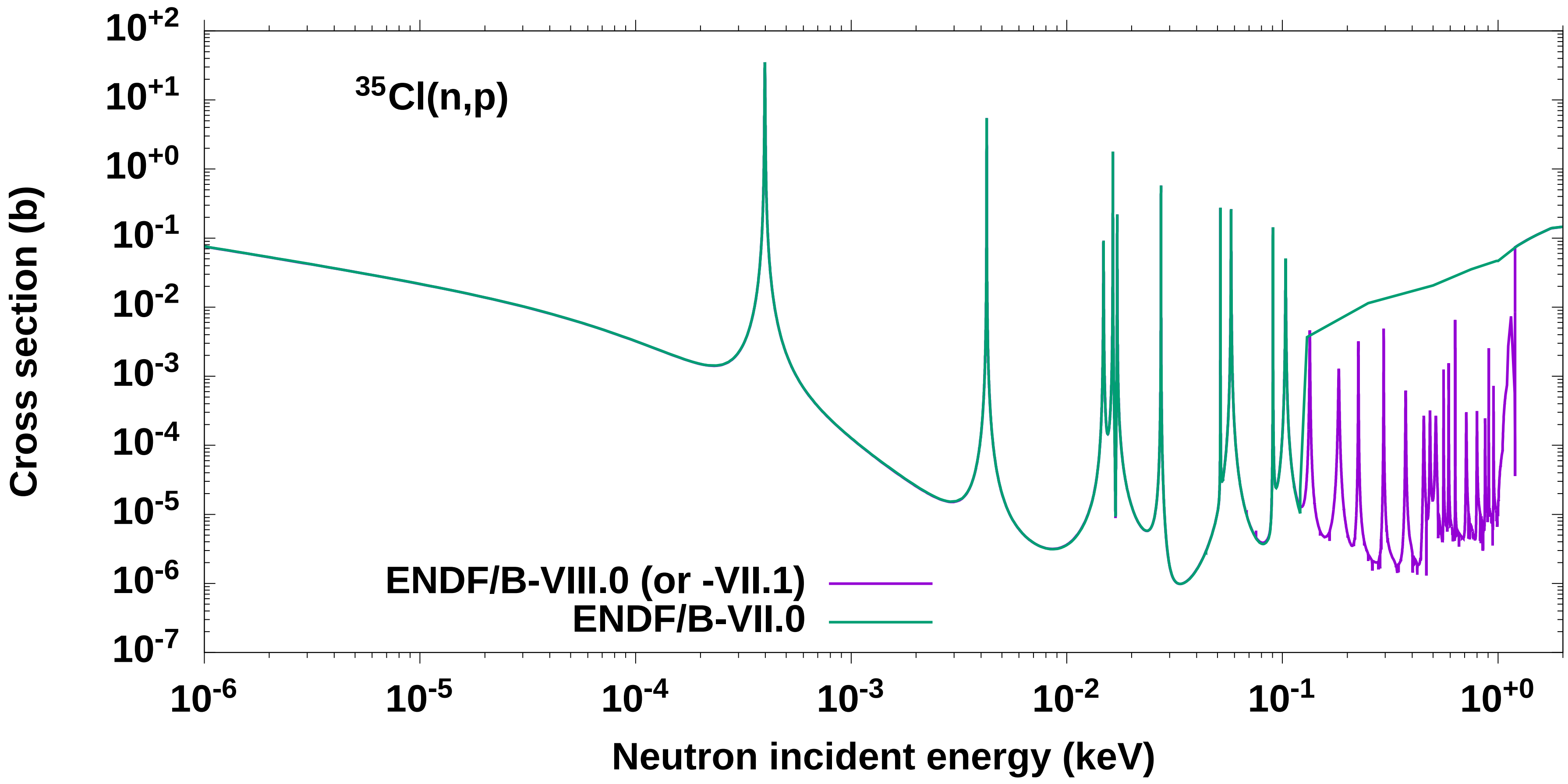
Introduction

- In the recently released ENDF/B-VIII.0 library the ^{35}Cl(n,p) cross section above 100 keV significantly differs from the ENDF/B-VII.0 library. This resulted in large differences in the predicted reactivity in nuclear reactor simulations
- The lack of experimental data for incident neutron energies above 100 keV does not allow a precise evaluation of the ^{35}Cl(n,p) reaction channel
- Evaluation of ^{35}Cl(n,p) cross section was included as one of the highest priorities in recent DOE calls for proposals within the Nuclear Data Interagency Working Group / Research Program
- Two proposals led by ORNL in collaboration with LANL were submitted
  - LAB 18-903 : *Measurement and Evaluation of the ^{35}Cl(n,p) Cross Section needed by Fast Nuclear Reactors* (2018)
  - LAB 19-2114: *Complete Measurement and New Evaluation of the ^{35}Cl(n,p) Cross Section in the Intermediate and Fast Energy Range needed by Fast Nuclear Reactors* (2019)
- Recent ^{35}Cl(n,p) cross section measurements
  - n_TOF measurement at EAR2 performed in November 2017 by Javier Praena. Reduction analysis of the measured data from thermal up to 500 keV is in progress
  - Measurement performed in January 2018 by Partha Chowdhury (University of Massachusetts Lowell)[1]

[1] M. Devlin et al. “A measurement of the ^{35}Cl(n,p) cross section in the MeV region”

Current Status in the ENDF/B-VIII.0 Library

- The n+^{35}Cl evaluation in the RRR is up to 1.2 MeV
- In ENDF/B-VIII.0 (or -VII.1), because of the limited energy range of the (n,p) measured data, the R-matrix analysis of the (n,p) reaction channel above 100 keV was estimated by using the (n,p) partial width and level density obtained from experimental data below 100 keV



Reactor Simulation and Safety Margin

- A simple 2D unit cell model of a molten chloride fast breeder reactor (MSBR) was generated using the SCALE code
- In order to maintain the desired fission rate within the core, the reactor control can be achieved by two types of rods

  (1) *Control rods* that can be actively inserted or withdrawn from the reactor core during reactor normal operation, fuel loading

  (2) *Safety rods* can provide independent shutdown capability and contain enough absorber material to terminate a fission chain reaction under any emergency situations
- In a MSBR, one control rod contributes to a net reactivity δk/k change for about 0.08%. A change of reactivity rate of about 0.01% per second is adequate for a normal control of the reactor
- On the other hand, safety rods are necessary to take care of unforeseen situations such as salt flow blocks in the circulating loops. One safety rod contribute to a net reactivity change is about 1.5%. Two out of the four safety rods should be sufficient under any conceivable conditions and a total worth of the safety rods are adequate for the worst-case accident
- The changes in the ^{35}Cl(n,p) cross sections (Figure on slide 4) led to very large differences in the calculated effective multiplication factor k_{eff} and to a reactivity difference $\rho = \delta k/k > 1\%$
- This variation in reactivity was roughly equivalent to the change generated by one safety rod worth or more than 10 control rods

NCSP Plan in Appendix B

- **Measurement (LANL)**: Plan to be performed and completed between FY2021–FY2022 (as currently in Appendix B)

- **R-matrix evaluation and validation (ORNL)** : Plan to be performed and completed between FY2021–FY2023

- Including newly measured (n,p) cross sections, e.g. measured data from n_TOF (Praena) and Lowell (Chowdhury)
- Updating the set of resonance parameters in $B_c = -l$ boundary condition
- Including an estimate of the minor (n,α) reaction channel to ensure the partial cross sections add up to the total cross section
- Including the direct capture component (about 400 mb at thermal energy) by introducing an imaginary part to real R-matrix channel radii

- **Validation (ORNL)**: the n+^{35}Cl cross section will be validated with particular emphasis on fast reactor applications

Acknowledgments

This work was supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy

Thank you!