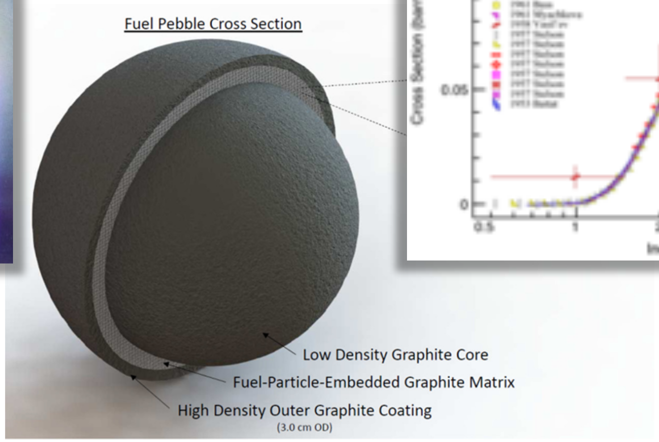
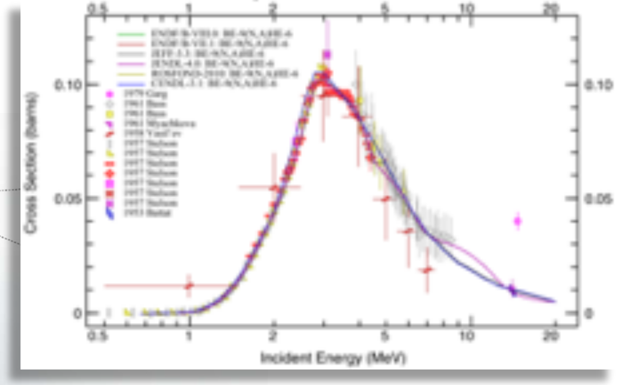


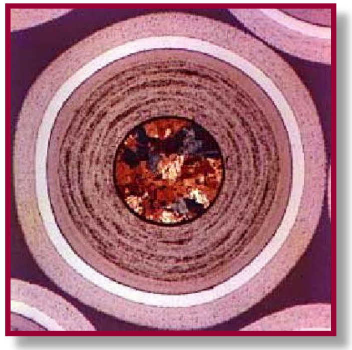

# Impact of nuclear data on the design of fluoride cooled reactors

Massimiliano Fratoni | University of California, Berkeley

Workshop for Applied Nuclear Data Activities

January 23, 2019

# Fluoride-cooled high-temperature reactors feature solid fuel and molten salt coolant

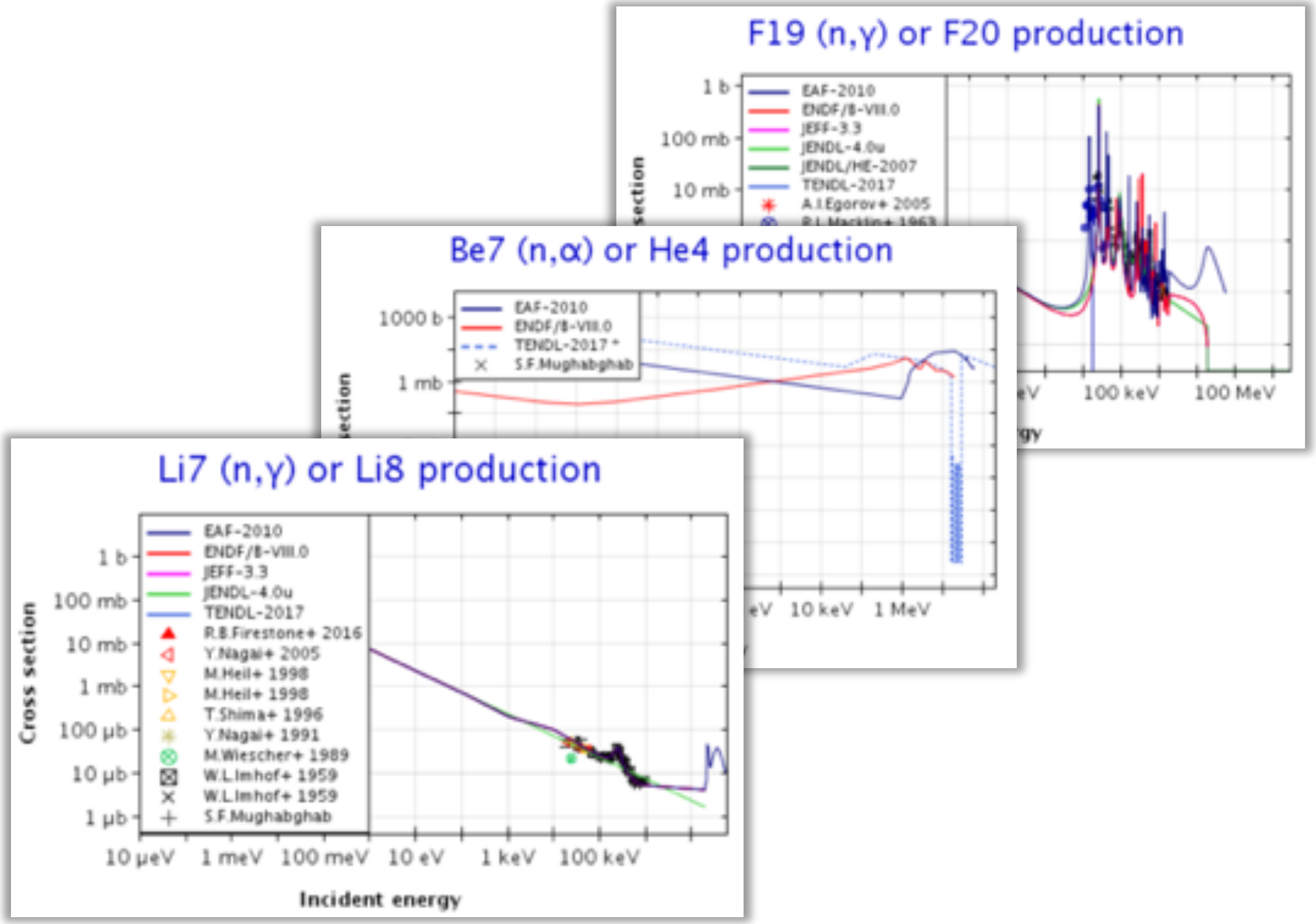


- **Solid fuel**: fuel is in the form of pebbles, plates, or blocks containing coated-particle fuel (TRISO) developed for high-temperature gas-cooled reactors (HTGRs) with failure temperatures >1650°C

- **Coolant**: high-temperature, low-pressure liquid-salt coolant ($^7Li_2BeF_4$) with freezing point of 460°C and boiling point >1400°C (transparent)

# Data of importance for FHRs

- Thermal scattering data
  - Graphite
  - Flibe
- Cross sections of $^{19}$F, $^{9}$Be, $^{6/7}$Li

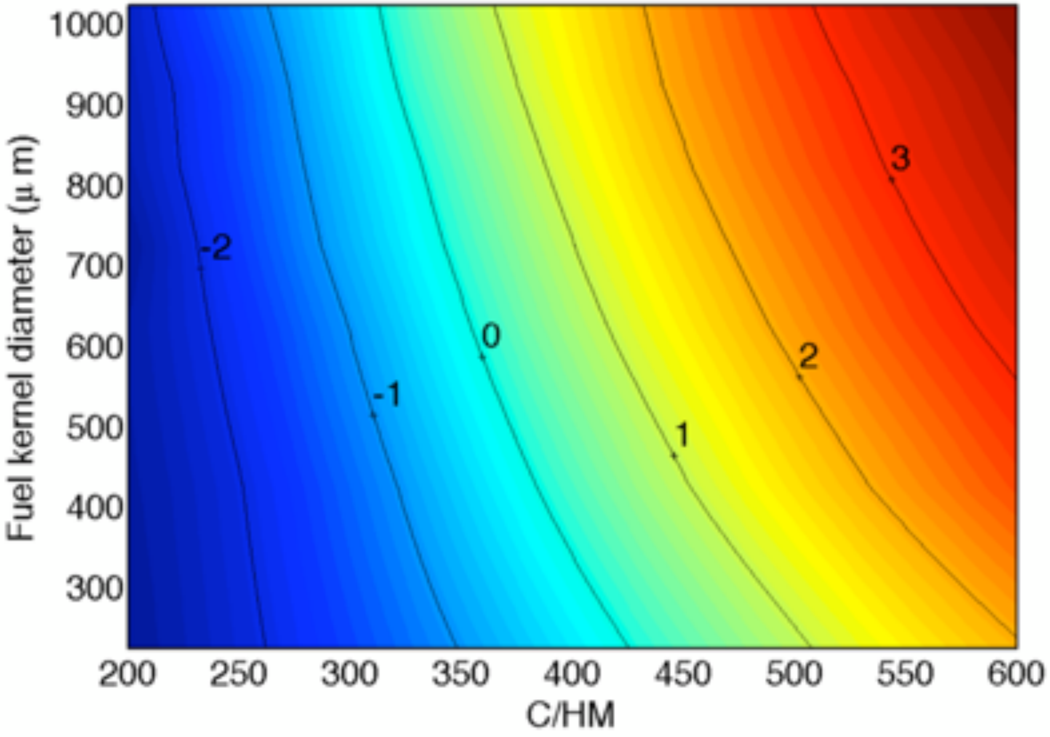


# The major source of uncertainty in flibe is $^{7}Li$ capture cross section

| Reaction | Uncertainty, pcm |
|---|---|
| $^{7}Li$ capture | 1,240 |
| $^{235}U$ nu | 379 |
| $^{238}U$ capture | 214 |
| $^{19}F$ capture | 172 |
| $^{235}U$ capture | 157 |
| $^{235}U$ fission | 138 |
| $^{12}C$ capture | 138 |
| $^{12}C$ elastic | 121 |
| Total | 1,380 |

# FHRs feature relatively small coolant density reactivity coefficients

- Coolant density (temperature) reactivity feedback in FHRs is a fine balance between flibe absorption and moderation
  - Positive feedback from reduced absorption
  - Negative feedback from reduced moderation (spectrum hardening)
- Coolant temperature feedbacks can only be achieved if flibe has a significant contribution to moderation




*Coolant temperature reactivity feedback (pcm/K) as a function of carbon-to-heavy metal ratio*

# Uncertainty in the coolant density feedback is also dominated by $^{7}Li$ capture

| Reaction | Relative uncertainty, % |
|---|---|
| $^{7}Li$ capture | 31.30 |
| $^{19}F$ capture | 4.33 |
| $^{19}F$ elastic | 2.10 |
| $^{7}Li$ elastic | 1.67 |
| $^{9}Be$ capture | 0.99 |

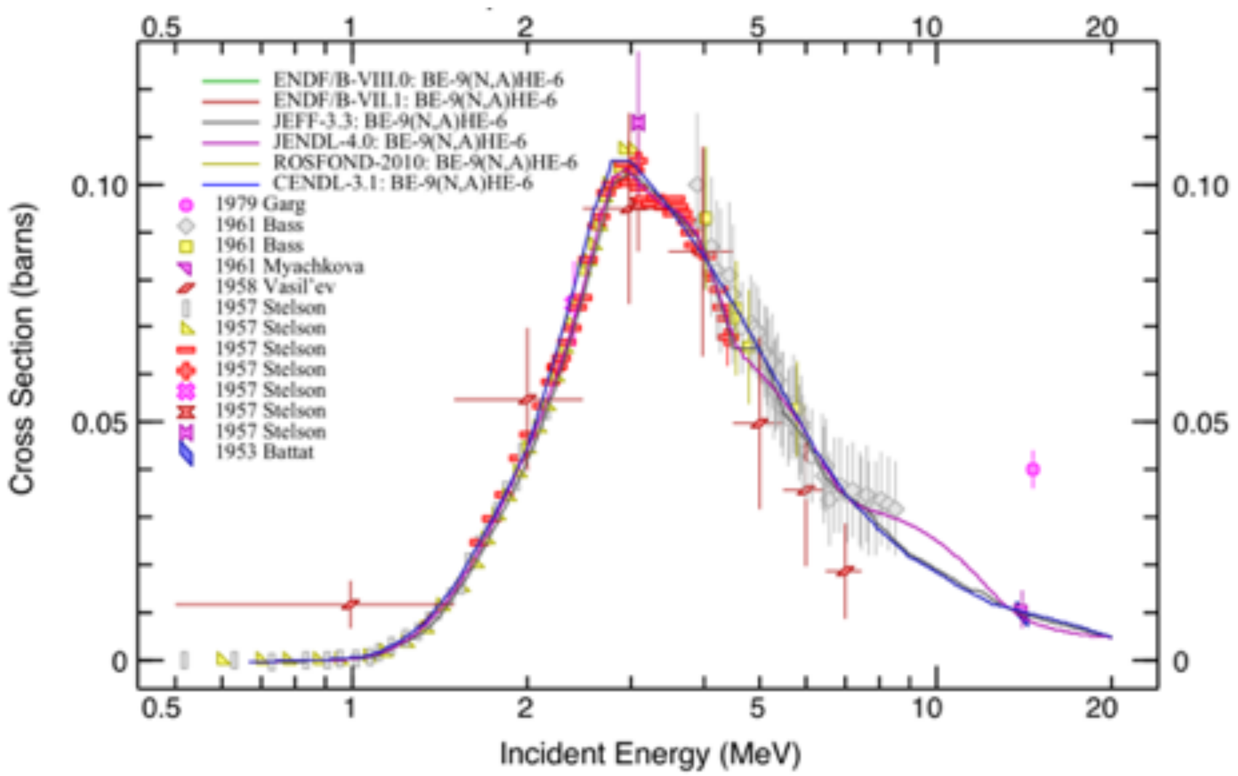
# $^{9}$Be(n,alpha) cross section determines $^{6}$Li concentration

- $^{6}$Li cannot be completely eliminated as it produced by (n,alpha) reactions on $^{9}$Be

- Concentration of $^{6}$Li reaches an equilibrium that depends on cross sections

$$N_{Li-6} = \frac{\sigma^{\alpha}_{Be-9}}{\sigma^{abs}_{Li-6}} N_{Be-9}$$

- 1 ppm of $^{6}$Li is worth ~175 pcm reactivity




*$^{9}$Be(n,alpha) cross section*

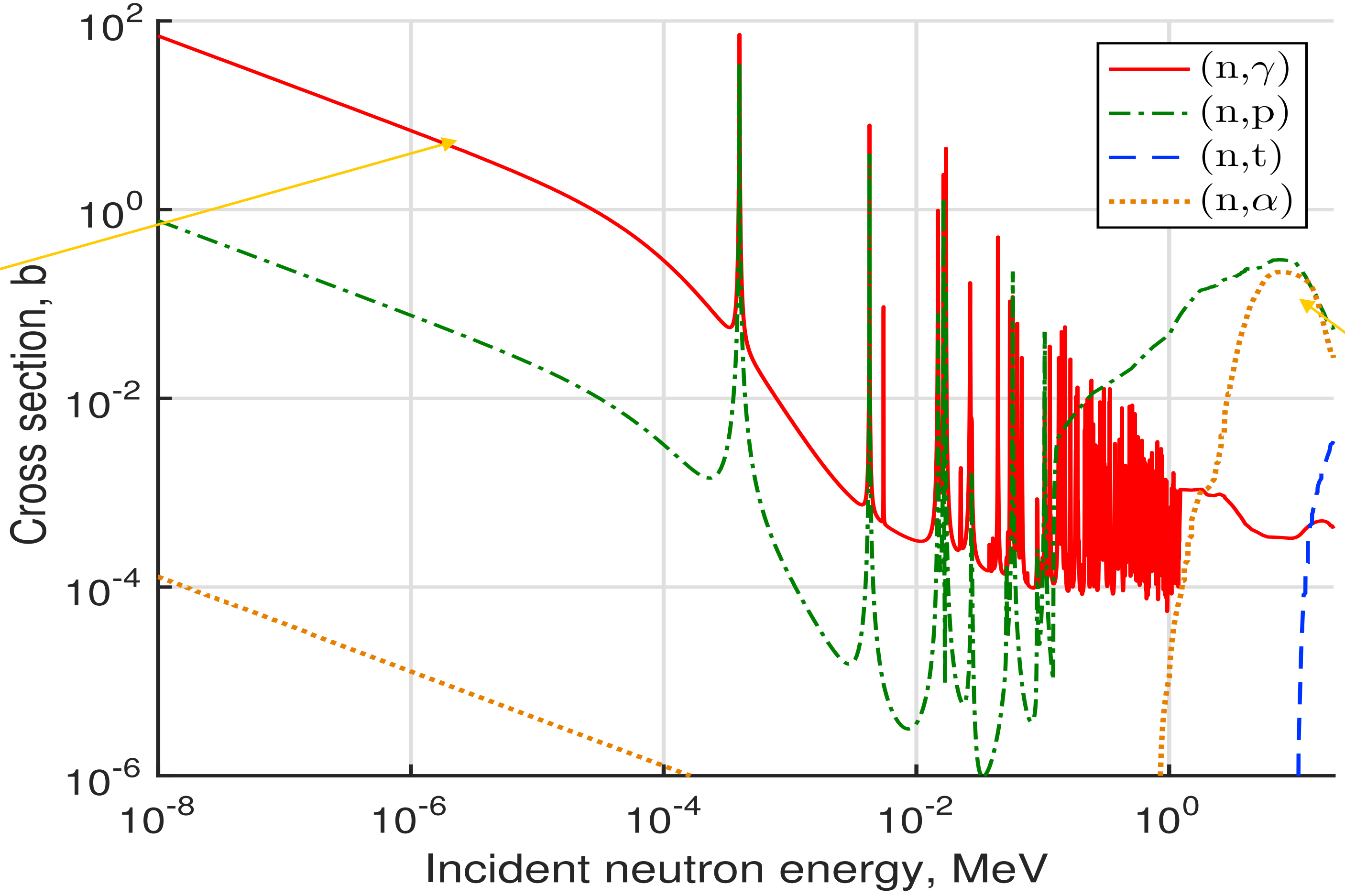
# FHR and fluoride molten salt reactors share similar data needs

Uncertainty from nuclear data for the effective multiplication factor of the Molten Salt Reactor Experiment

| Reaction | Uncertainty, pcm |
|---|---|
| $^{235}$U nu | 373 |
| $^{12}$C elastic | 263 |
| $^{238}$U capture | 257 |
| $^{7}$Li capture | 197 |
| $^{235}$U capture | 171 |
| $^{19}$F elastic | 143 |
| $^{235}$U fission | 120 |

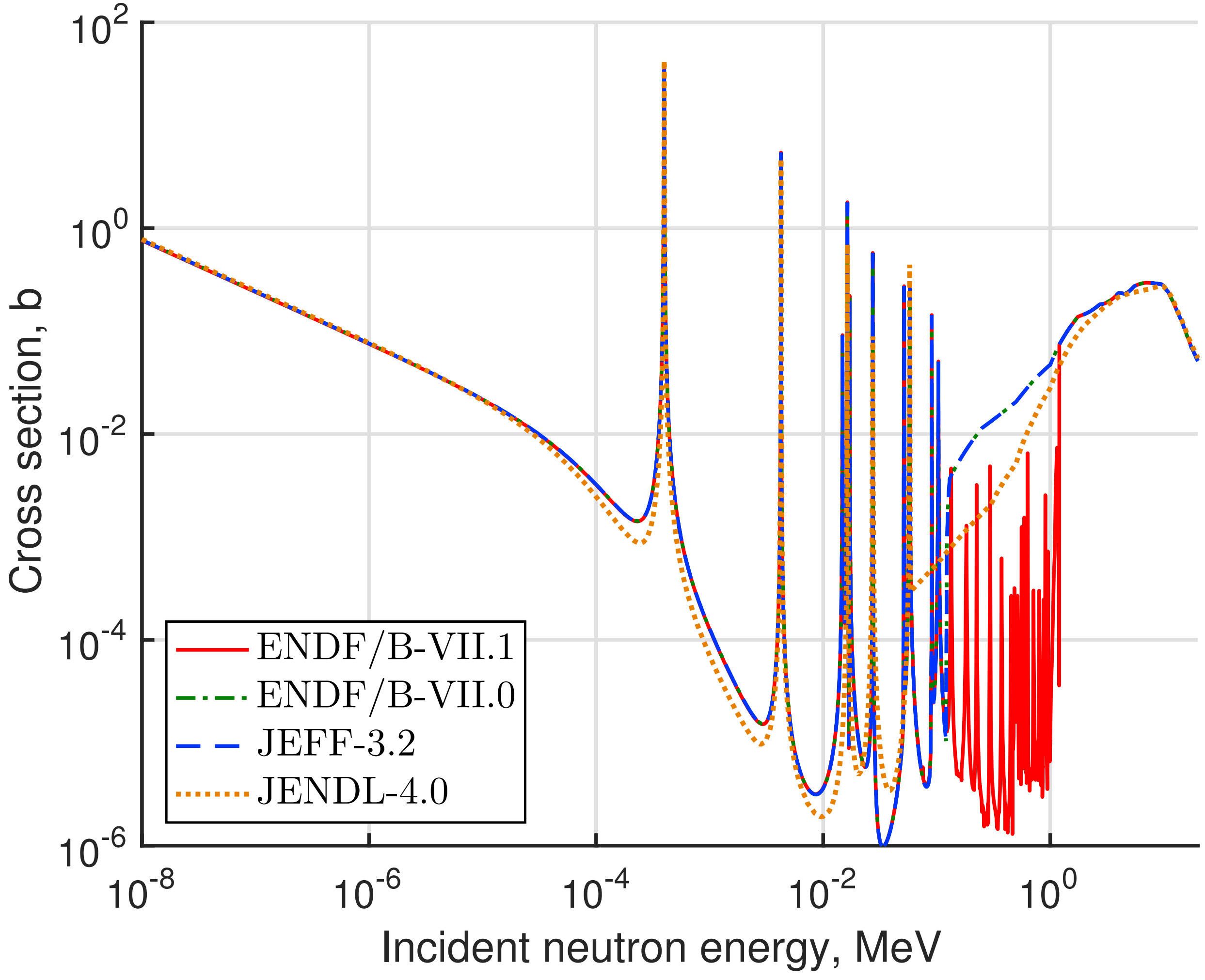
# Chloride molten salt reactors are impacted by the large uncertainties in $^{35}$Cl cross sections

Neutron loss and Cl-36 in thermal spectrum by (n,$\gamma$) reactions



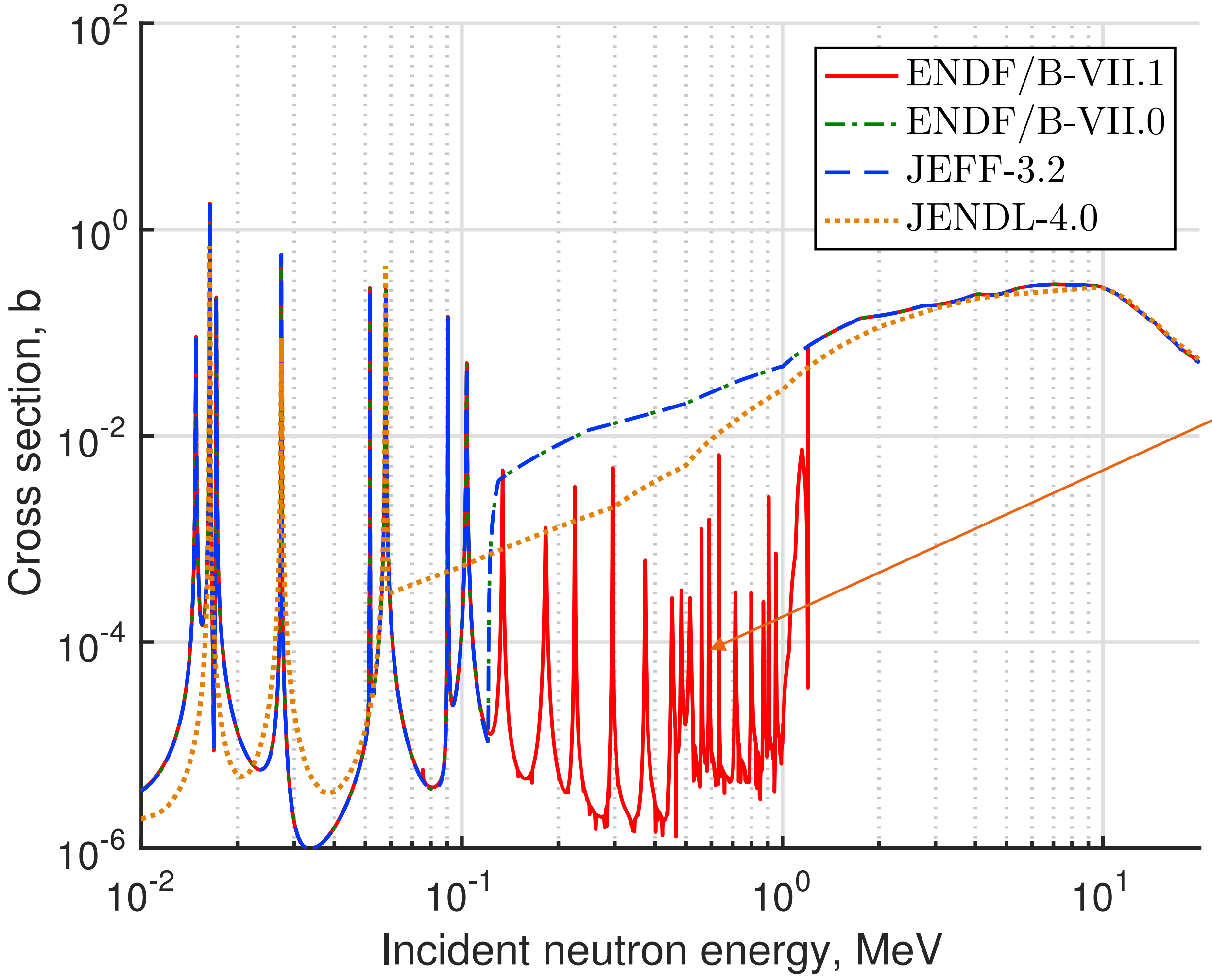

Neutron loss in fast spectrum by (n,p) reactions

# There are large discrepancies between data libraries for $^{35}$Cl(n,p) cross section




ENDF/B-VII.0
and
JEFF-3.2
completely
overlap

# The main discrepancies are in the fast energy range




ENDF/B-VII.1 includes detailed resonances between ~0.1 MeV and ~1 MeV

This is more realistic than the smooth trend adopted so far by other libraries

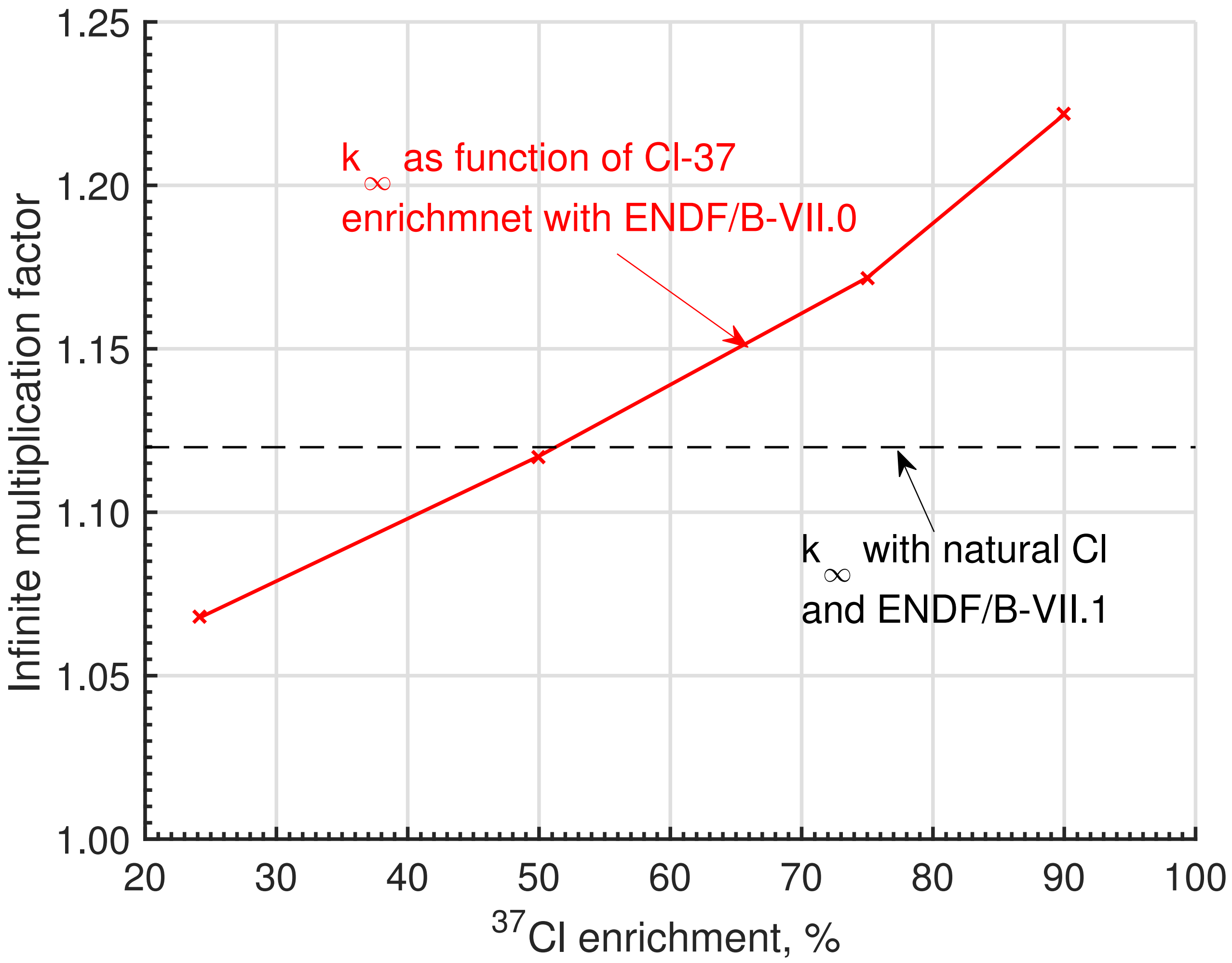
The cross section in this region is 2-3 orders of magnitude smaller when using ENDF/B-VII.1 vs. ENDF/B-VII.0

In fast systems most neutrons are in this energy region

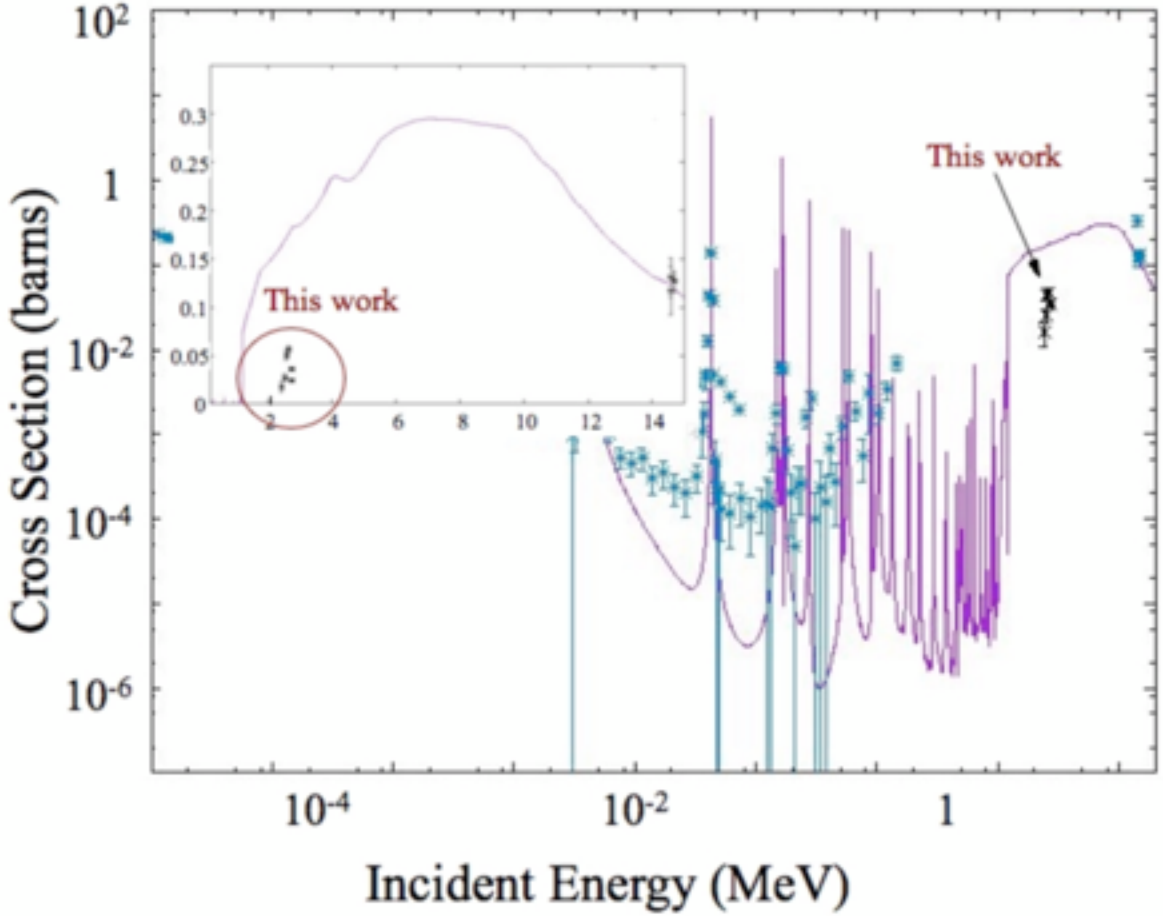
# The difference between ENDF/B-VII.0 and ENDF/B-VII.1 is 5200 pcm!

| Quantity | ENDF/B-VII.0 | ENDF/B-VII.1 | Difference |
|---|---|---|---|
| $k_\infty$ | 1.06789 ± 0.00023 | 1.11989 ± 0.00021 | +0.05200 |
| (n,p) effective cross section, b | 0.01947 | 0.01109 | -0.00839 |
| (n, $\gamma$) effective cross section, b | 0.00245 | 0.00246 | +0.00001 |

# Switching from ENDF/B-VII.0 to ENDF/B-VII.1 is equivalent to increase $^{37}$Cl enrichment to about 50%

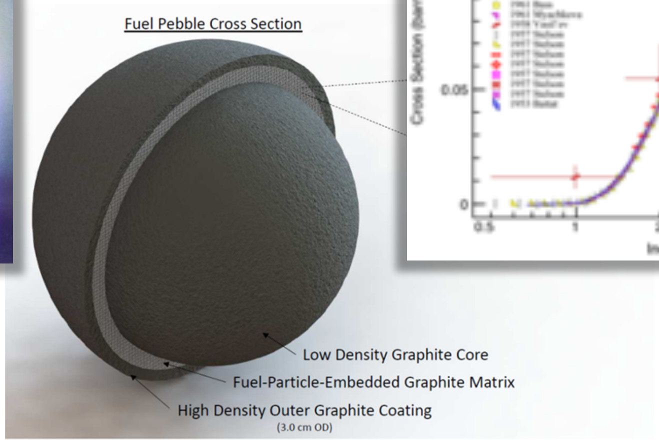


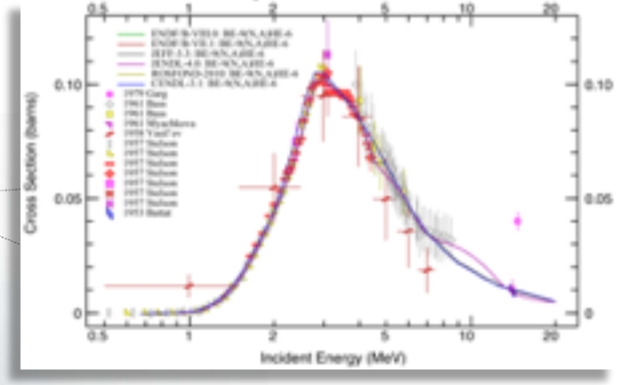
# New measurements were made at UC Berkeley




J. Betchelder *et al.*, Evidence of non-statistical properties in the $^{35}Cl(n,p)^{35}S$ cross section

Berkeley
UNIVERSITY OF CALIFORNIA




# Impact of nuclear data on the design of fluoride cooled reactors

Massimiliano Fratoni | University of California, Berkeley

Workshop for Applied Nuclear Data Activities

January 23, 2019