Adjustment and validation of Fe-56 data with shielding benchmarks

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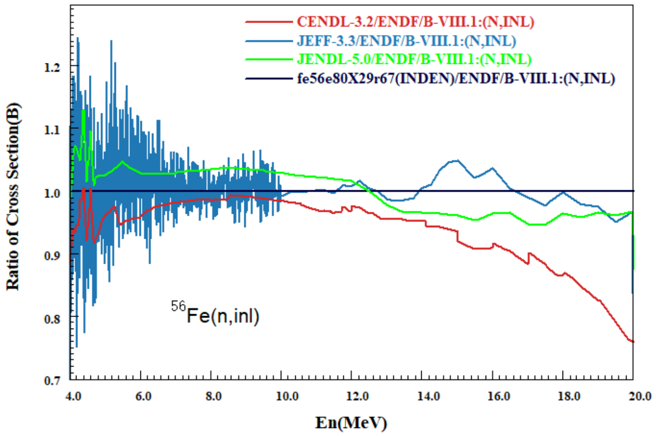
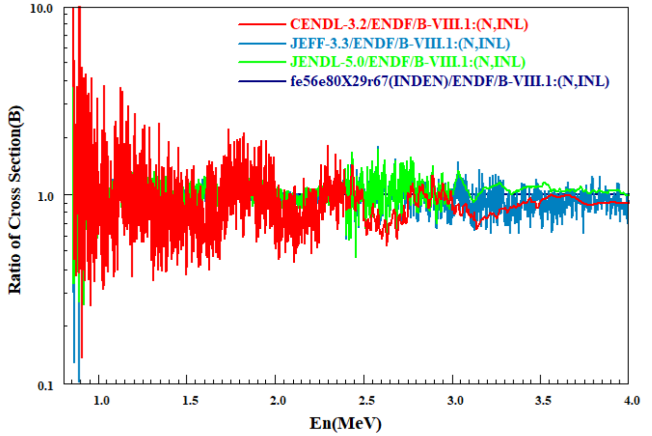
Contents

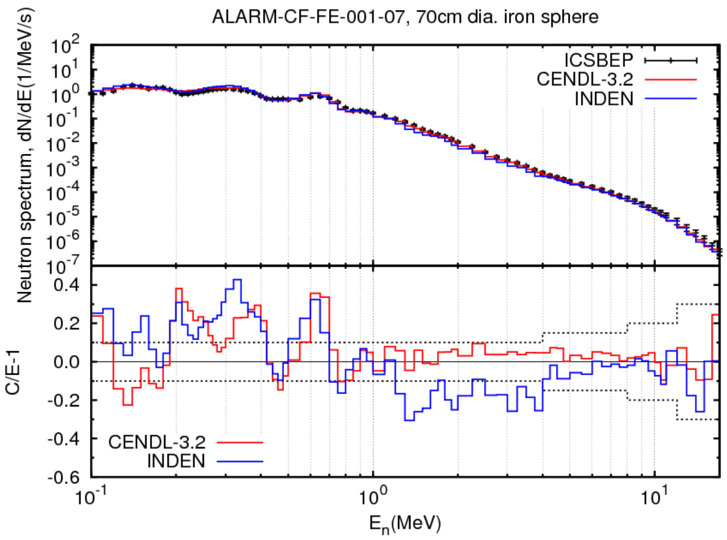
1 Background

- **Iron is an important structural material and shielding material in nuclear reactors, but there are still significant differences in the evaluation of ^{56}Fe(n, inl) cross sections in the latest evaluation files.**
  - **Above 4MeV, difference between different evaluations is below 25%.**
  - **Below 4MeV, the difference in evaluation data between companies is gradually exceeding 100%.**

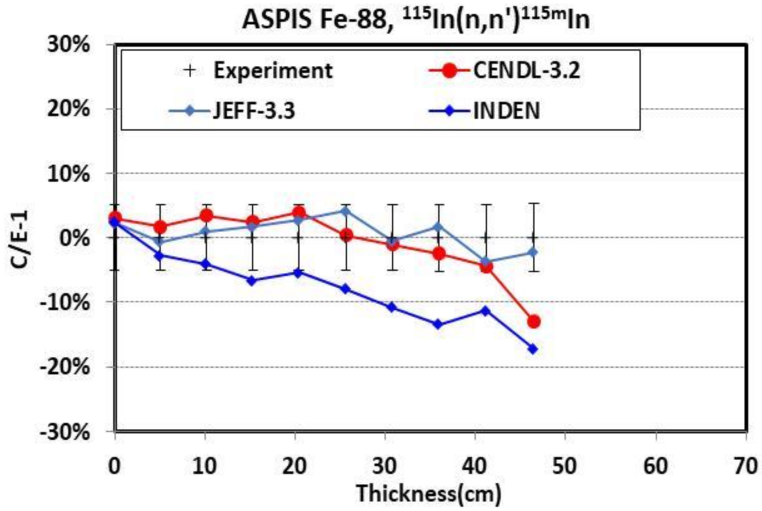




- **Shielding benchmark testing results shows the performance of iron data in shielding calculation still needs to be improved.**
- **In order to improve the accuracy of shielding calculation and provide quantitative feedback for the nuclear data evaluation, nuclear data adjustment study based on shielding experiments was purposed.**



Comparison of cal. and exp. neutron leakage spectra from the 70cm-dia. IPPE iron sphere



Comparison of cal. and exp. $^{115}In(n,n')^{115m}In$ reaction rates of ASPIS/Fe88 exp.

2 Adjustment of Fe-56 data with the IPPE iron spheres

■ Methodology

Assume the adjusted group constant C' and posterior integral quantities I' are the optimal estimates in the maximum likelihood sense, then the nuclear data and covariance before and after the adjustment, as well as the integral quantities and covariance, should satisfy the maximum likelihood function.

$$L = \exp\left\{-\frac{1}{2}\left[\left(\frac{C'-C}{C}\right)^T M_r^{-1}\left(\frac{C'-C}{C}\right)+\left(\frac{I'-I_e}{I_e}\right)^T V_r^{-1}\left(\frac{I'-I_e}{I_e}\right)\right]\right\}$$

The cross section adjustment factor can be expressed as

$$\delta C = -\left(M_r S^T W^{-1}\right) d$$

Where,

Integral bias

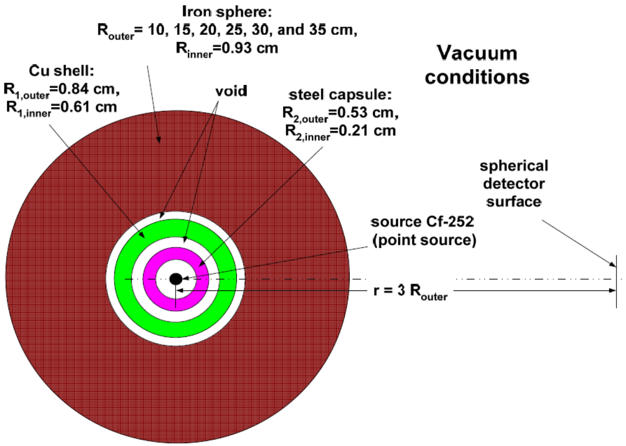
$$d = \left\{ d_j = \frac{i_c - i_e}{i_c}, \quad j = 1,2,\cdots m \right\}$$

$$W = SM_r S^T + FV_r F$$

$(F\ is\ diagonal\ matrix\ of\ Ie/Ic)$

■ Shielding benchmark for adjustment

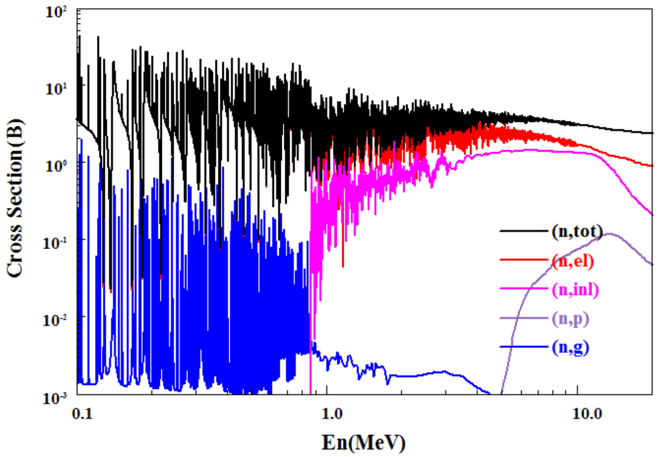
- 6 set of neutron leakage spectra with evaluated experiment uncertainties were given by the IPPE iron sphere benchmark.



Schematic diagram of the ALARM-CF-FE-001 exp.

■ Differential data to be adjusted

- target：Fe-56
- Reaction channel：(n,el), (n,inl) and (n,γ)
- Data to be adjusted ：cross section

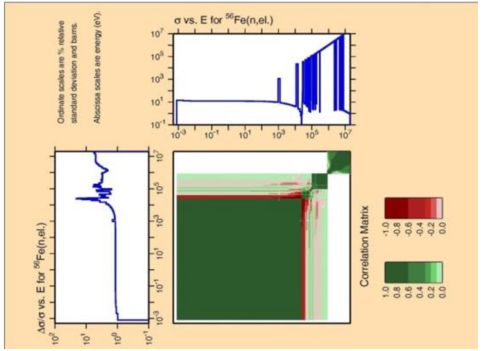


Comparison of the cross sections of major reactions for Fe-56

- # Input differential data
  - Priori XS. and covariance.

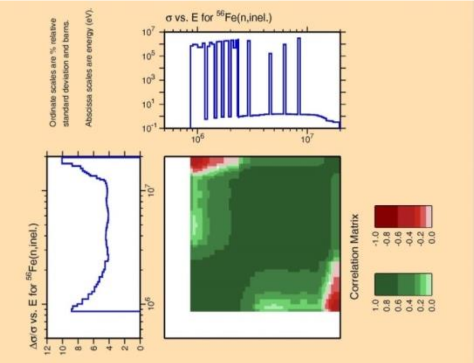
- **PENDF/ACE: JEFF-3.3/Fe-56，processed by NJOY2016.**

- **Covariance：JEFF-3.3 ，processed by NJOY2016 with the energy group structure of Vitamin-B6-199**



The covariance of ^{56}Fe(n,el) cross section (JEFF-3.3)

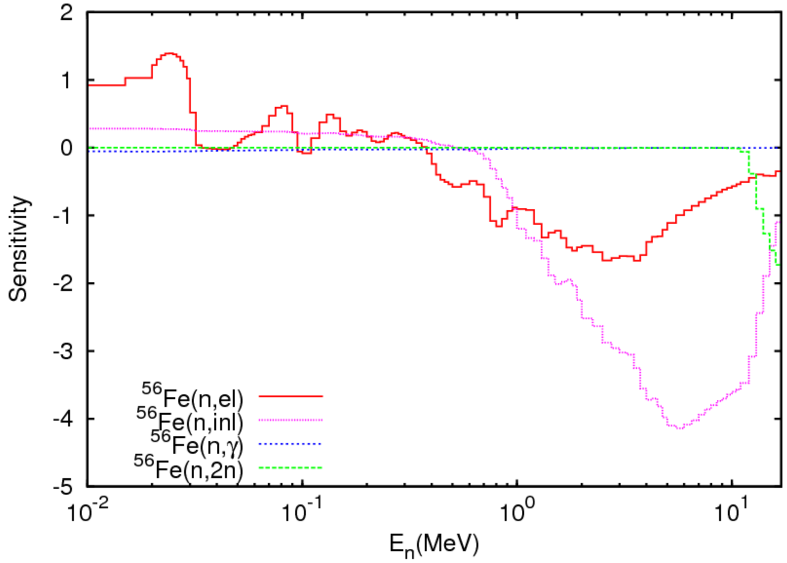
Strong Correlation



The covariance of ^{56}Fe(n,inl) cross section (JEFF-3.3)

Input sensitivity

- **The sensitivity matrix for neutron leakage spectrum calculated with MCNP**
  - Energy region：0.01-17MeV，116g；
  - perturbation amplitude ：±1%；
  - Reaction channel ：(n,el),(n,inl), (n,γ)

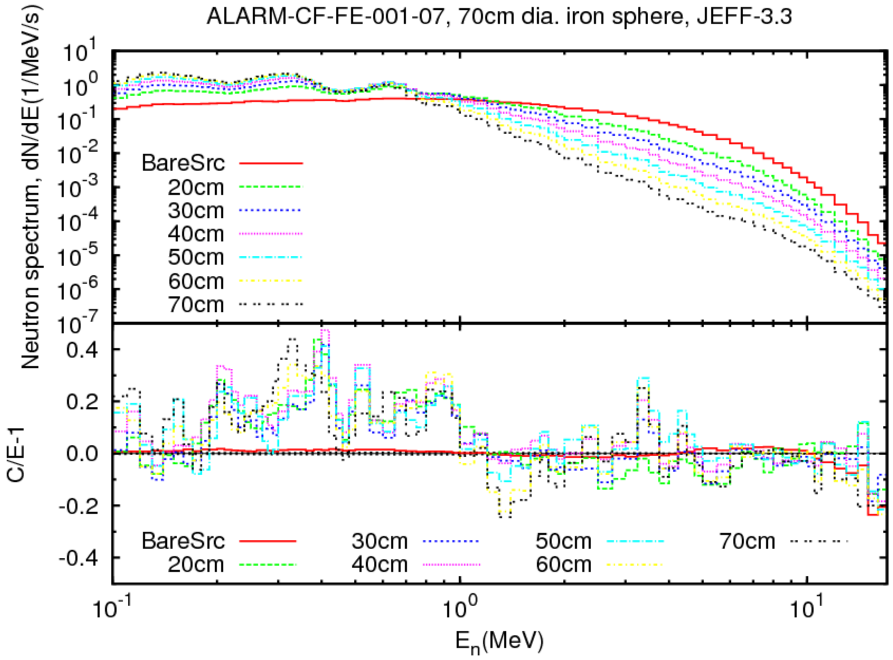


The sensitivity of the neutron leakage spectrum of the 70cm-dia. IPPE iron sphere benchmark to the neutron reaction cross sections of Fe-56 (with all energy groups changed simultaneously).

✓ **>1MeV：the sensitivity to (n,inl) reaction cross sections are larger than those to (n,el).**

Priori integral quantities and uncertainty

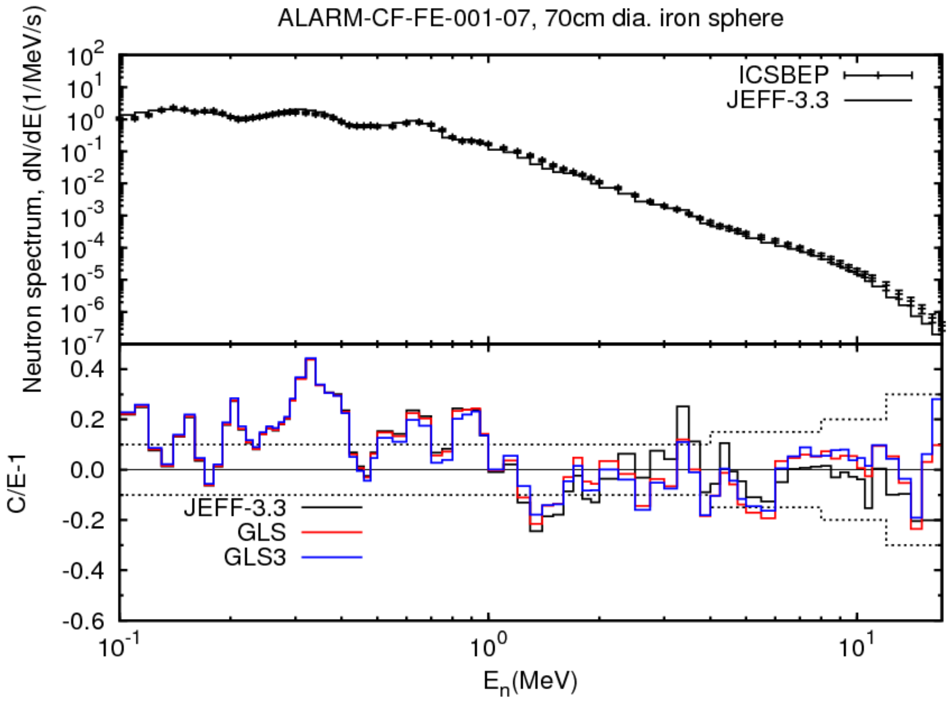
- **Neutron leakage calculated by MCNP**
  - Energy range：0.01-17MeV；
  - Samples: 6



The neutron leakage spectra from the IPPE iron spheres calculated with the JEFF-3.3

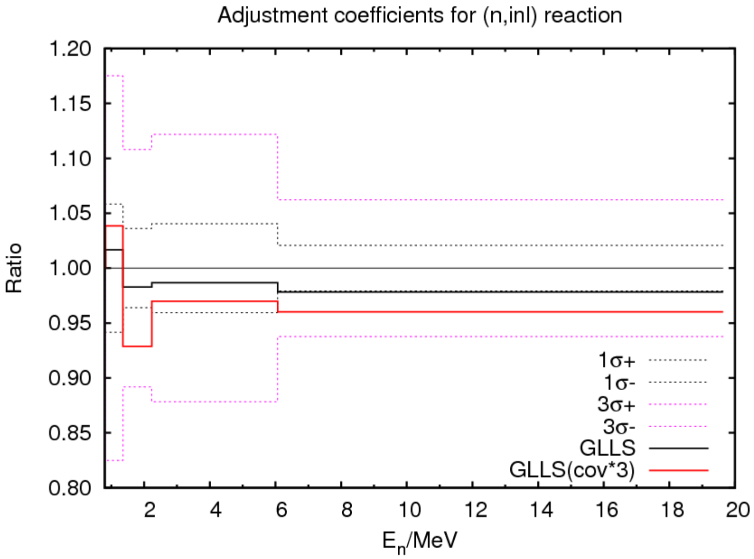
The adjusted neutron leakage spectrum

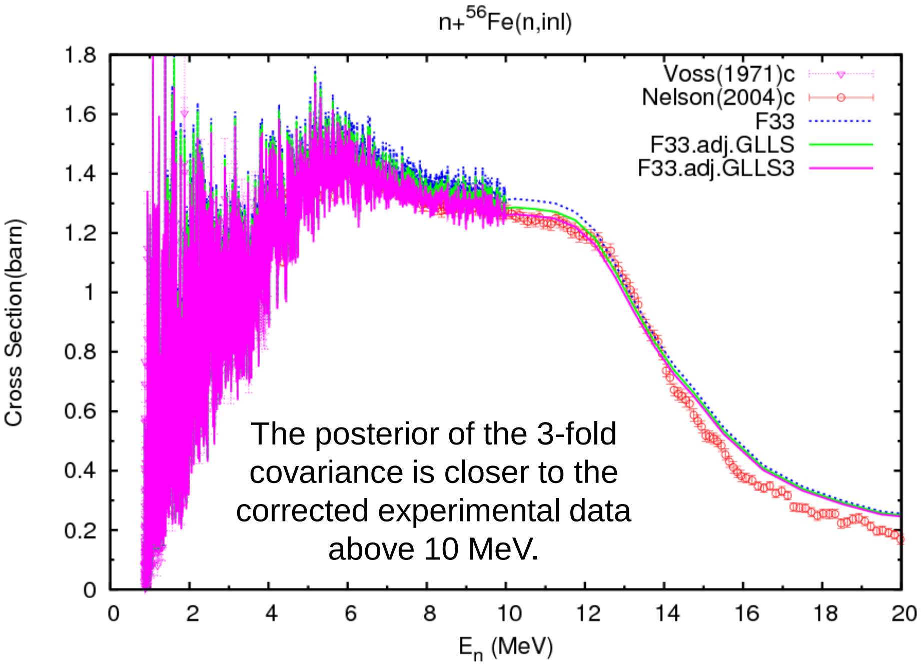
- After the adjustment, the MeV energy group of the neutron leakage spectrum is significantly improved, and the keV energy region is basically unchanged.
- The 3-fold covariance was slightly better adjusted than the 1-fold covariance.
- The difference between the calculated and experimental values cannot be completely eliminated by adjustment.



Comparison of the calculated neutron leakage spectrum from the IPPE 70cm diameter iron sphere before/after adjustment

▪ Adjustment factors and posterior of (n, inl) cross-section



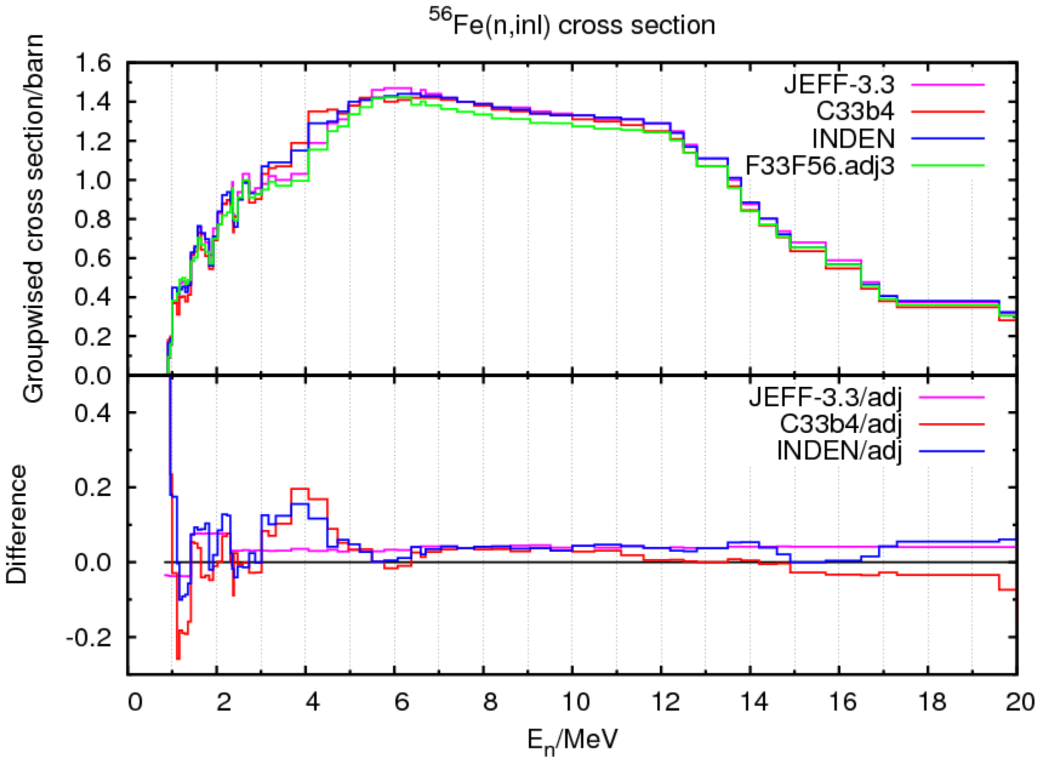


- The adjustment factor is larger than 1 standard deviation.
- The strong correlation covariance results in poor granularity of the adjustment coefficients.

Comparison of priori and posterior ^{56}Fe(n,inl) cross-sections with revised experimental data

■ Comparison of the adjusted (n, inl) cross-section with the evaluated values

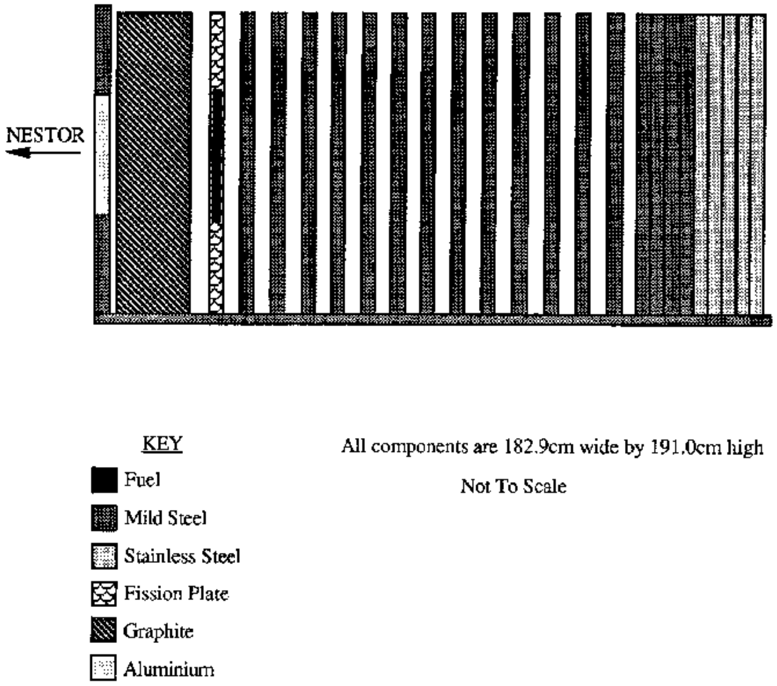
In the energy range of 11-15MeV, the adjusted cross-section is closer to the C33b4 revision of Fe-56 data.



3 Validation of adjusted data with ASPIS/Fe88

▪ ASPIS/Fe88

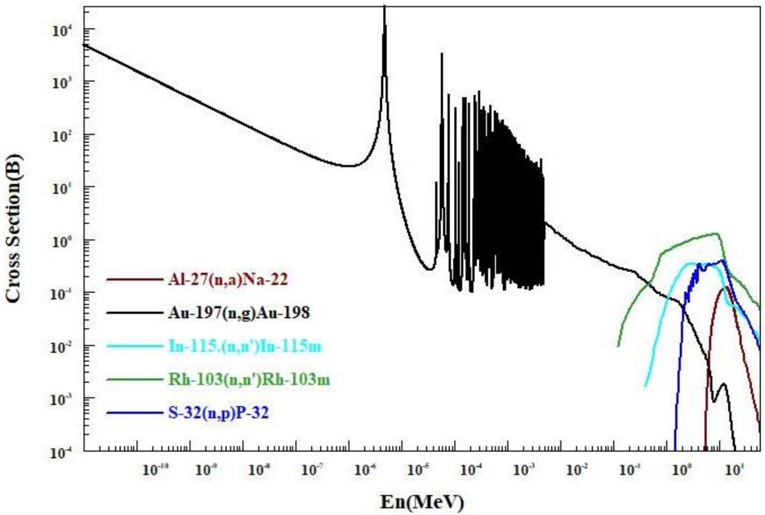
- The ASPIS/Fe88 experiment is a deep penetration shielding benchmark experiment carried out on the ASPIS shielding device of the NESTOR reactor.
- In the experiment, the activation method was used to measure the reaction rates of the reactions $^{197}Au(n,\gamma)^{198}Au$, $^{32}S(n,p)^{32}P$, $^{115}In(n,n')^{115m}In$, $^{103}Rh(n,n')^{103m}Rh$ and $^{27}Al(n,\alpha)^{24}Na$ among 13 mild steel plates with a thickness of 5.1 cm (at 14 positions from A2 to A15).



■ Validation ability of the ASPIS/Fe88

The effective threshold and sensitive energy region of different types of activation foils.

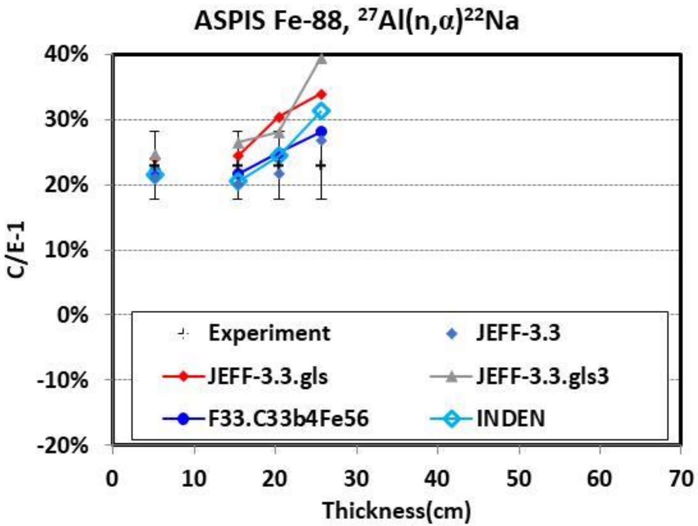
activation foil	reaction	Effective threshold energy (MeV)	Sensitive energy range(MeV)
Au-197(Cd)	$^{197}Au(n,\gamma)^{198}Au$	5.0E-7	1.45E-6 ~ 1.58E-3
Rh-103	$^{103}Rh(n,n')^{103m}Rh$	0.4	7.95E-02 ~ 5.77
In-115	$^{115}In(n,n')^{115m}In$	1.2	0.334~6.38
S	$^{32}S(n,p)^{32}P$	2.9	1~8.6
Al-27	$^{27}Al(n,\alpha)^{22}Na$	7.2	5.22~14.6

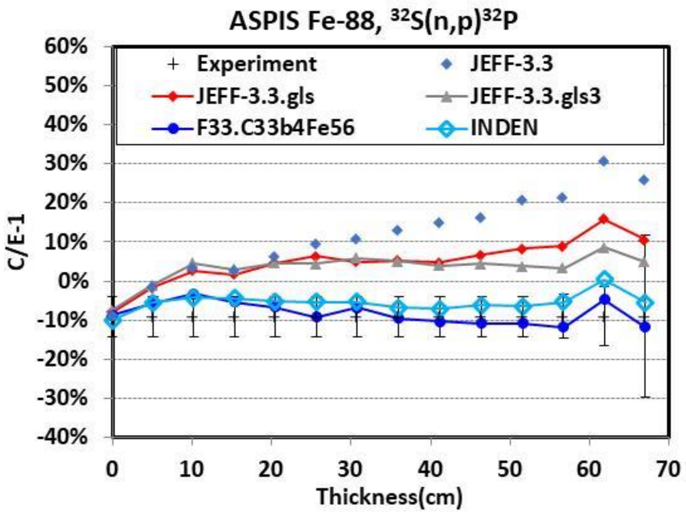


Comparison of cross sections of activation foils

Validation results with the ASPIS/Fe88 experiment

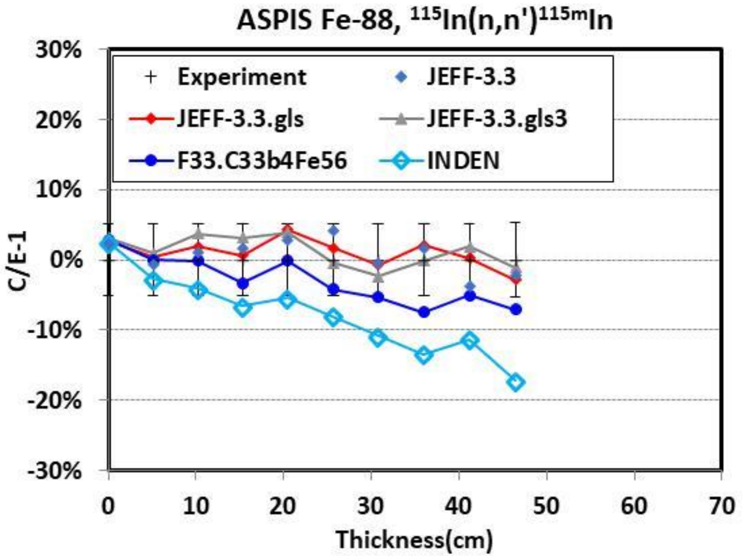
- **Al[5.22~14.6]：the adjusted $^{27}Al(n,\alpha)$ reaction rates turn worse.**
- **S[1~8.6]： The posterior of $^{32}S(n,p)$ reaction rate was significantly improved, with the adjustment using 3-fold covariance being even better, and the maximum calculation deviation was reduced from 31% to 9%.**

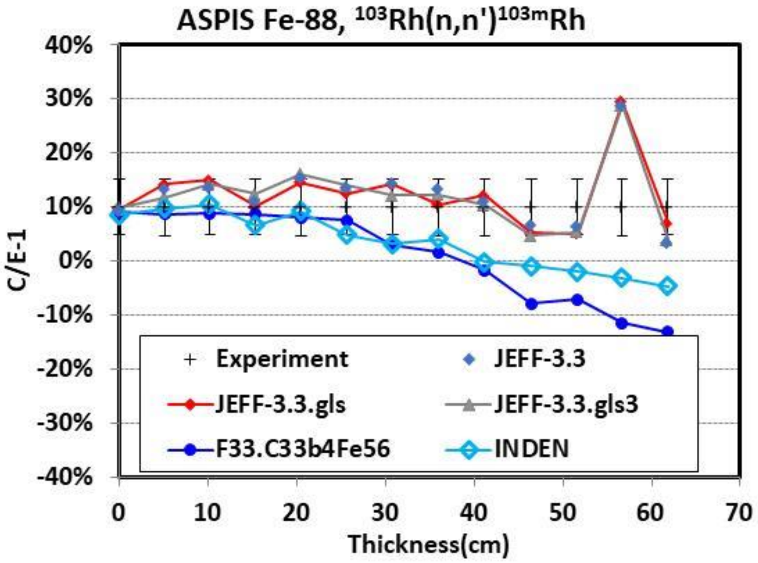




Validation results with the ASPIS/Fe88 experiment

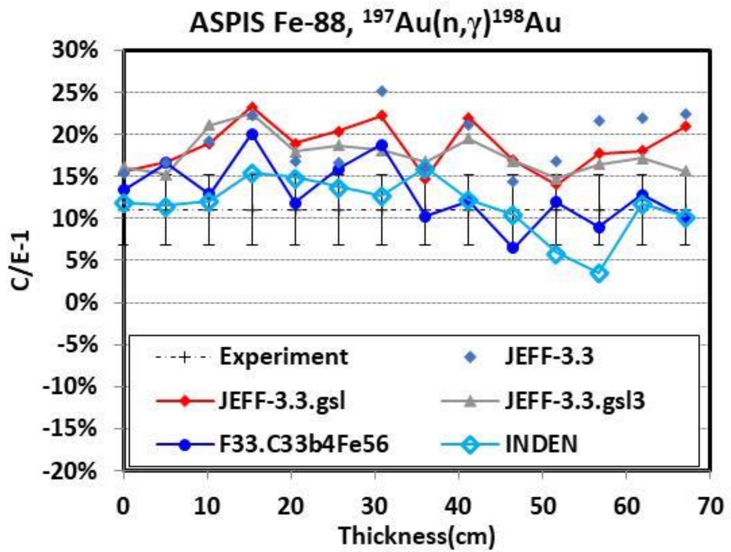
- **In[0.334~6.38]/ Rh[7.95E-02 ~ 5.77]： The adjusted reaction rate deviation was basically the same as that before adjustment, which was better than the results of the combination of JEFF-3.3 and C33b4Fe56.**





Validation results with the ASPIS/Fe88 experiment

- **Au[1.45E-6 ~ 1.58E-3]： The adjusted reaction rate bias was improved, and the improvement was more pronounced when the 3-fold covariance was used.**



4 Summary

- **Based on the IPPE iron sphere benchmark and the Fe-56 data from JEFF-3.3, the adjustment coefficients of (n,el), (n,inl) and (n,γ) reaction cross sections were obtained .**
- **The adjusted inelastic scattering cross section is closer to the evaluation value of C33b4 in the 10-15 MeV energy region.**
- **The adjusted neutron leakage spectrum calculation results have been partially improved ；**
- **The ASPIS/Fe88 experiment was used to test the posterior data, and it was found that the adjusted result of the 3-fold covariance was better, and the maximum calculated deviation of the ^{32}S(n,p) reaction rate decreased from 31% to 9%. However, the calculation bias of the ^{27}Al(n,α) reaction rate was increased.**

Thank you for your attention!