Sensitivity and uncertainty analysis of major isotopes on the k_{eff} of the startup DNRR core with HEU fuel using MCNP6 and ENDF/B-VIII.0 library

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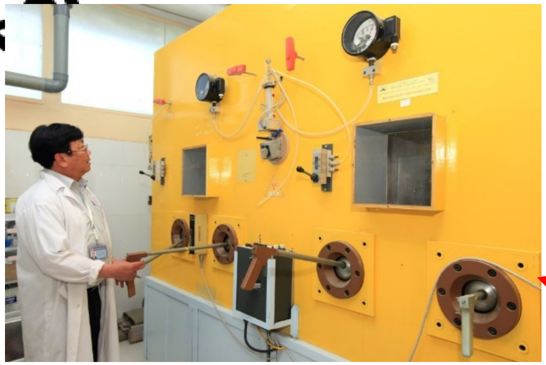
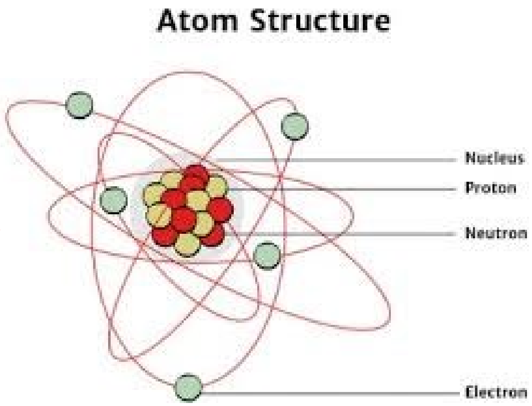
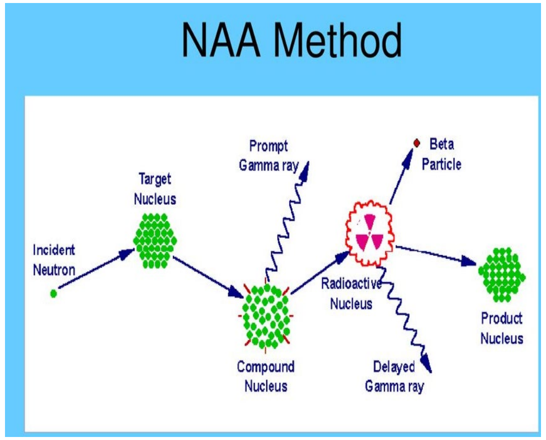
1. Introduction for DNRR







1. Introduction for DNRR

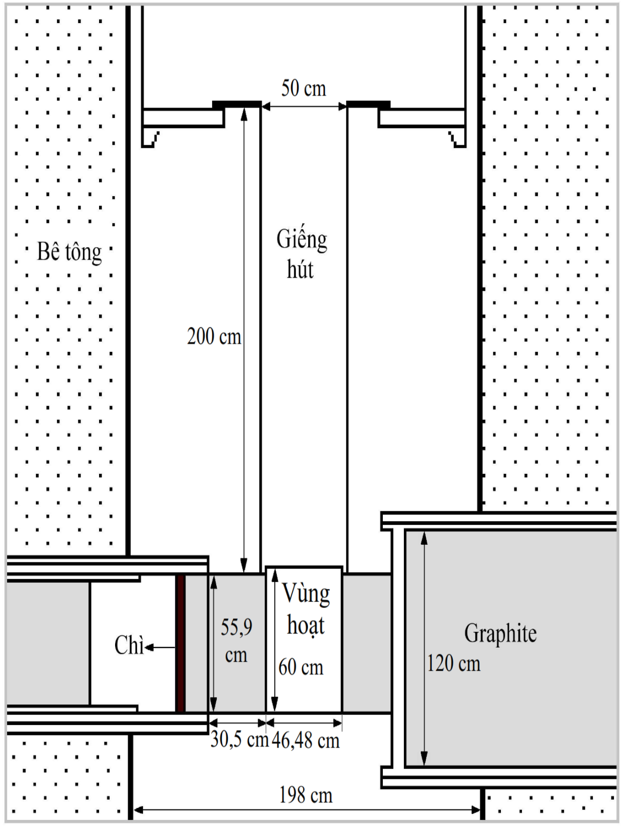


Fig 1: Vertical Cross section of DNRR

Table 1*: Specification of the DNRR with HEU fuel*

Specification	Description
Reactor type	Pool type
Nominal thermal power	500 kW
Moderator and Coolant	Light water
Cooling mechanism	Natural convection
Reflector	Graphite, Beryllium and water
Active core height	60 cm
Active core diameter	44,2 cm
Fuel bundle pitch	3,2 cm
Fuel	VVR-M2 type
HEU type	U-Al alloy, ^{235}U enrichment 36 wt%
Fuel cladding	Aluminum alloy SAV-1
Number of control rods	2 SR, 4 ShR, 1 regulating rod
Neutron measuring channels	6 (3 fission chamber detector, 3 ionization chamber detector)
Irradiation channel	4 (1 neutron trap, 1 wet channel, 2 dry channels)
Horizontal channel	4 (1 tangential channel, 3 radial channels)

1. Introduction for DNRR

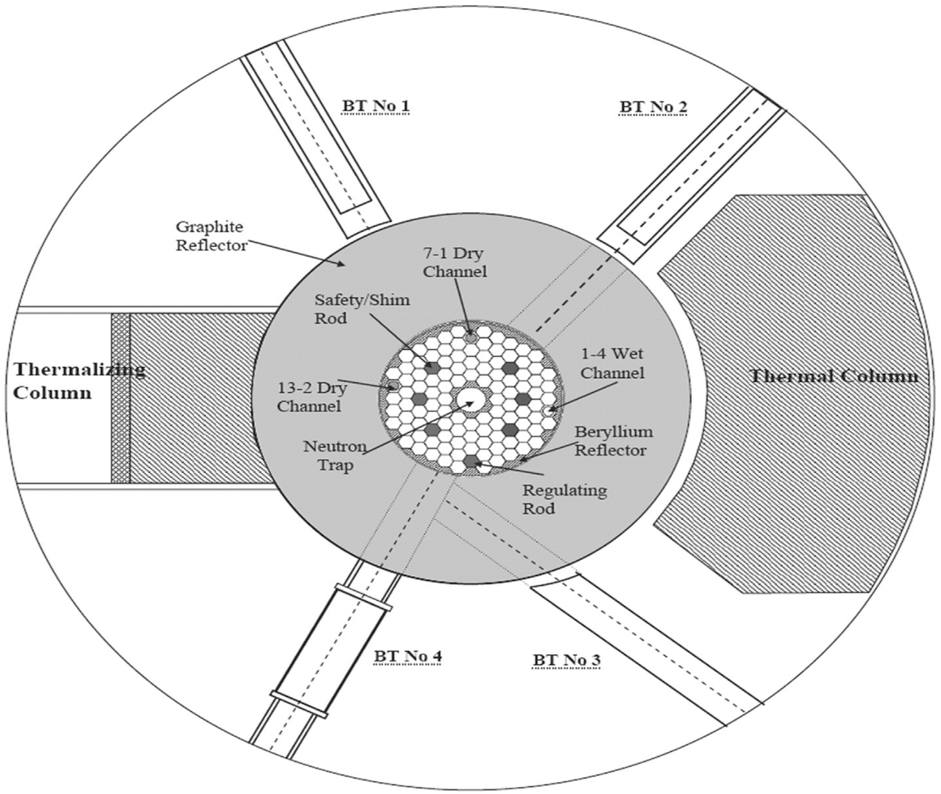


Fig 2: Horizontal Cross section of DNRR

The DNRR cores have been extensively simulated using a number of codes, such as SRAC, MCNP5... with nuclear data library EDND/B-VII.0; ENDF/B-VII.1; JENDL-4.0…

→ Reliability assessment of calculated data is performed by the MCNP6 program with the ENDF/B-VIII.0 kernel data library.

2. Methods for sensitivity and uncertainty analysis

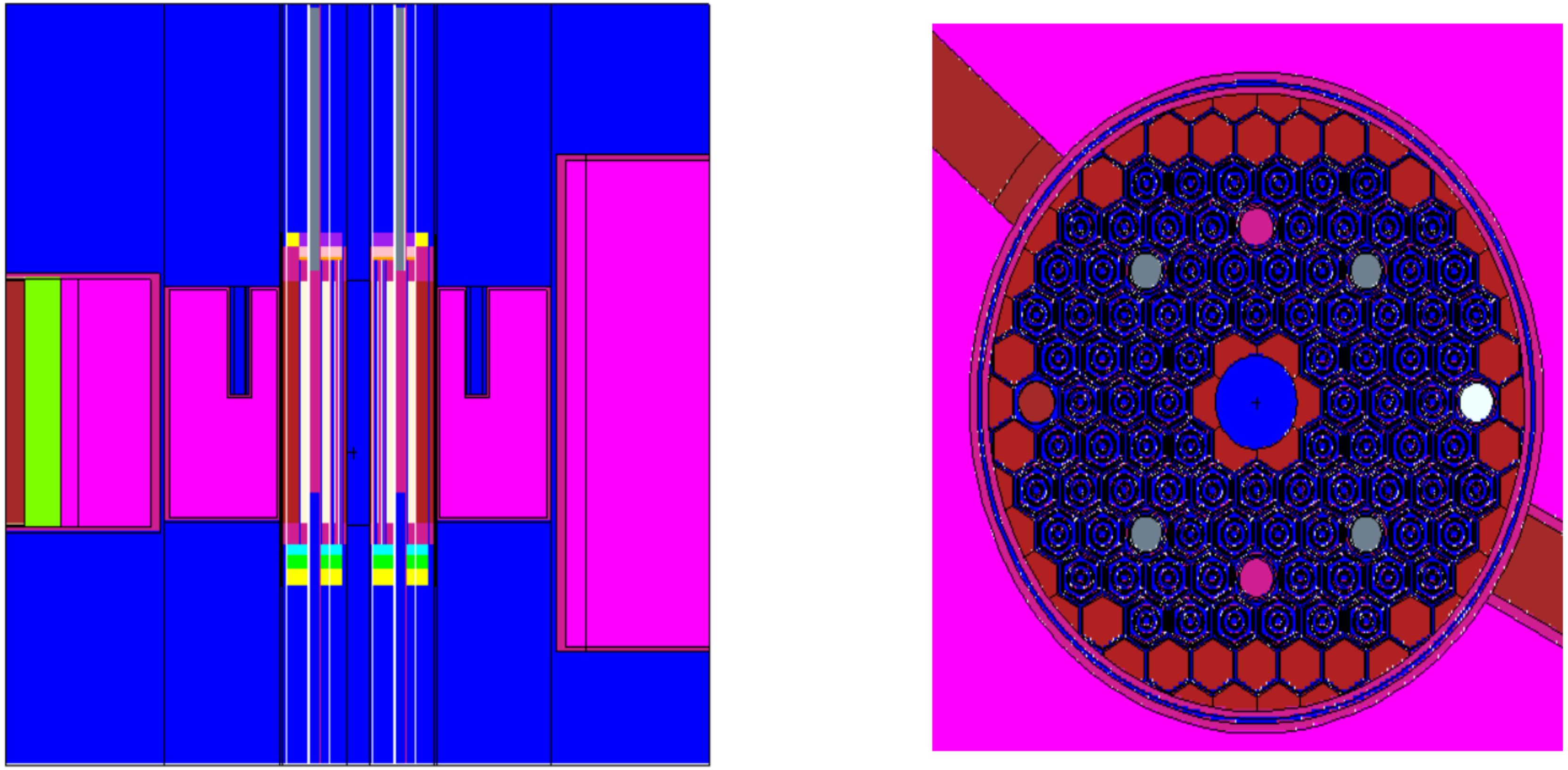


Fig 3: *MCNP6 model of the DNRR core with 88 HEU fuel bundles*

2. Methods for sensitivity and uncertainty analysis

Sensitivity coefficients give the subsequent change in the integral parameter k due to a constant variation σ of cross sections.

$$S_k = \frac{\partial k}{\partial \sigma} . \frac{\sigma}{k} \quad (1)$$

Run MCNP6 with KSEN mode, we have sensitivity profiles dependent due to energies:

$$S = \begin{bmatrix} S_1 \\ S_2 \\ \vdots \\ S_{44} \end{bmatrix} \quad (2)$$

2. Methods for sensitivity and uncertainty analysis

The covariance matrix of the reactions of each isotope was processed with the ERRORR card by NJOY2016 with 44 energy groups.

$$\boldsymbol{C} = \begin{bmatrix} \boldsymbol{C}_{1,1} & \boldsymbol{C}_{1,2} & \cdots & \boldsymbol{C}_{1,44} \\ \boldsymbol{C}_{2,1} & \boldsymbol{C}_{2,2} & \cdots & \boldsymbol{C}_{2,44} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{C}_{44,1} & \boldsymbol{C}_{44,2} & \cdots & \boldsymbol{C}_{44,44} \end{bmatrix} \quad (3)$$

2. Methods for sensitivity and uncertainty analysis

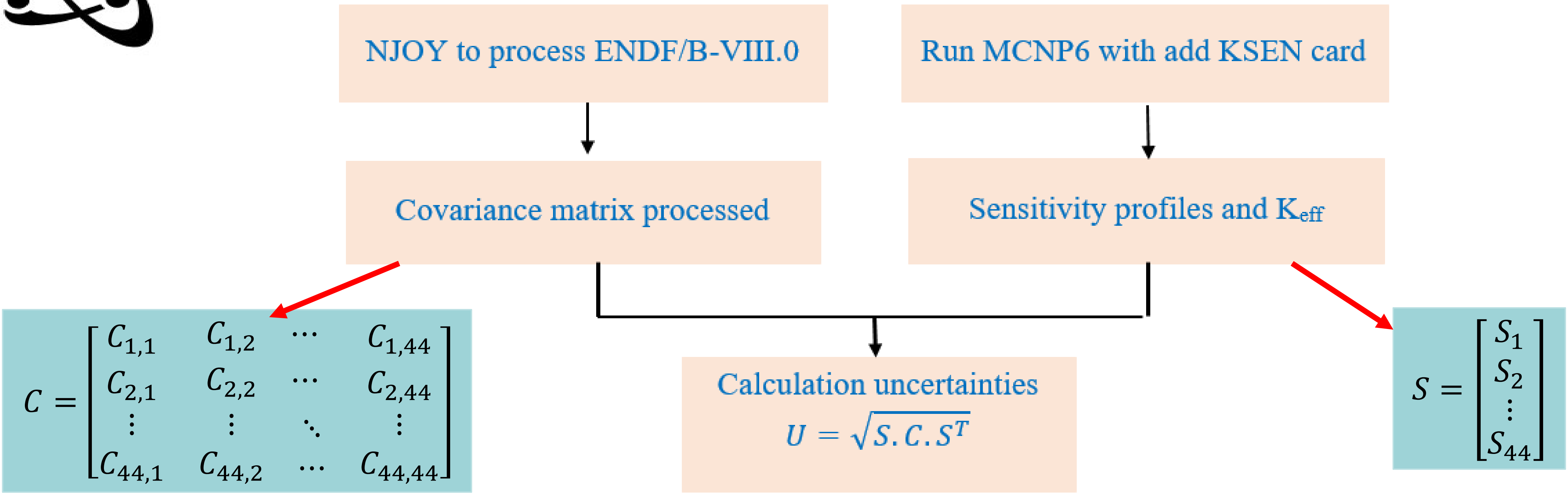


Fig 4: *Sensitivity and uncertainty calculation scheme*

The MCNP6 calculations were performed with 10^6 neutron of neutron history per cycle and run for 200 active cycles to ensure a statistic error of the k_{eff} within 6pcm

3. Result sensitivity and uncertainty of k_{eff}

$$K_{eff\ cal} = 0{,}99781 \pm 0{,}00006$$

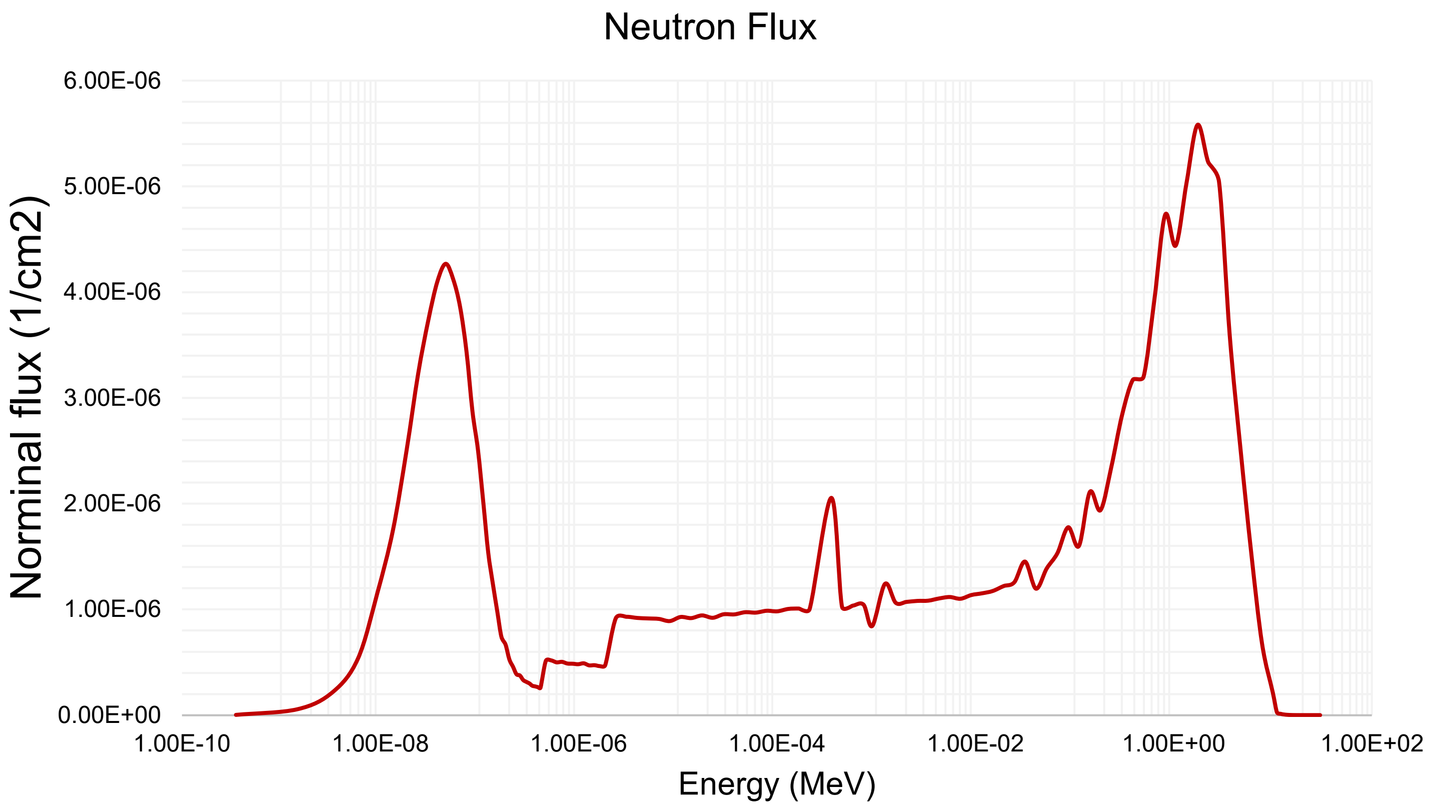


Fig 5: *Neutron spectrum of the DNRR core with 88 HEU fuel bundles*

3. Result sensitivity and uncertainty of k_{eff}

***Table 2**: Positive sensitivities of k_{eff} in the increasing direction*

Isotopes	Reaction	Sensitivity
U-235	Total ν	9.98E-01
U-235	Fission	3.52E-01
H-1	Elastic	2.89E-01
C- 12	Elastic	4.50E-02
Be-9	Elastic	4.40E-02
Al-27	Elastic	3.84E-02
O-16	Elastic	3.76E-02
C-nat (S(α,β))	Elastic	7.74E-03
C-nat (S(α,β))	Inelastic	6.93E-03
Fe-56	Elastic	2.65E-03
U-238	Total ν	2.12E-03
Be (S(α,β))	Inelastic	1.82E-03
U-238	Fission	1.46E-03

3. Result sensitivity and uncertainty of k_{eff}

Table 3*: Negative sensitivities of k_{eff} in the decreasing direction*

Isotopes	Reaction	Sensitivity
H-1	Capture	-1.48E-01
U-235	Capture	-1.24E-01
Al-27	Capture	-6.00E-02
U-238	Capture	-2.30E-02
B-10	n-α	-1.10E-02
Be (S(α,β))	Elastic	-4.08E-03
Be-9	Capture	-2.66E-03
Fe-56	Capture	-2.11E-03
U-234	Capture	-2.10E-03

3. Result sensitivity and uncertainty of k_{eff}

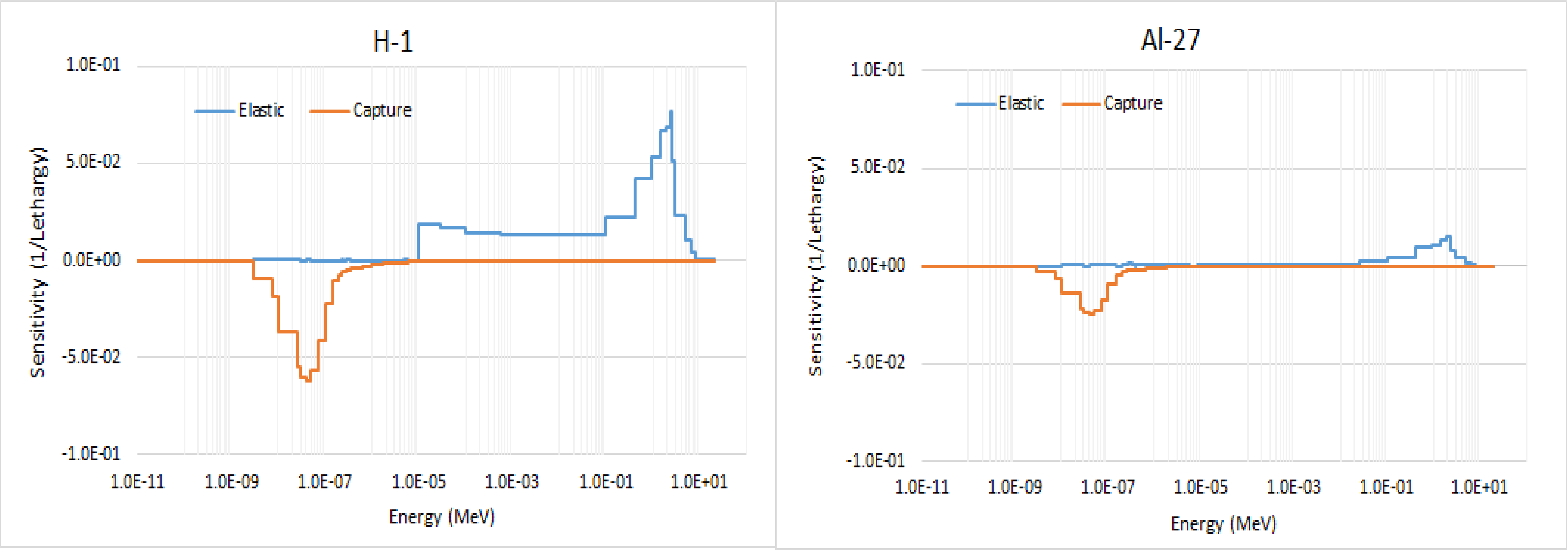


Fig 6: *Energy dependent sensitivities of k_{eff} to H-1 and Al-27 cross sections*

3. Result sensitivity and uncertainty of some isotopes

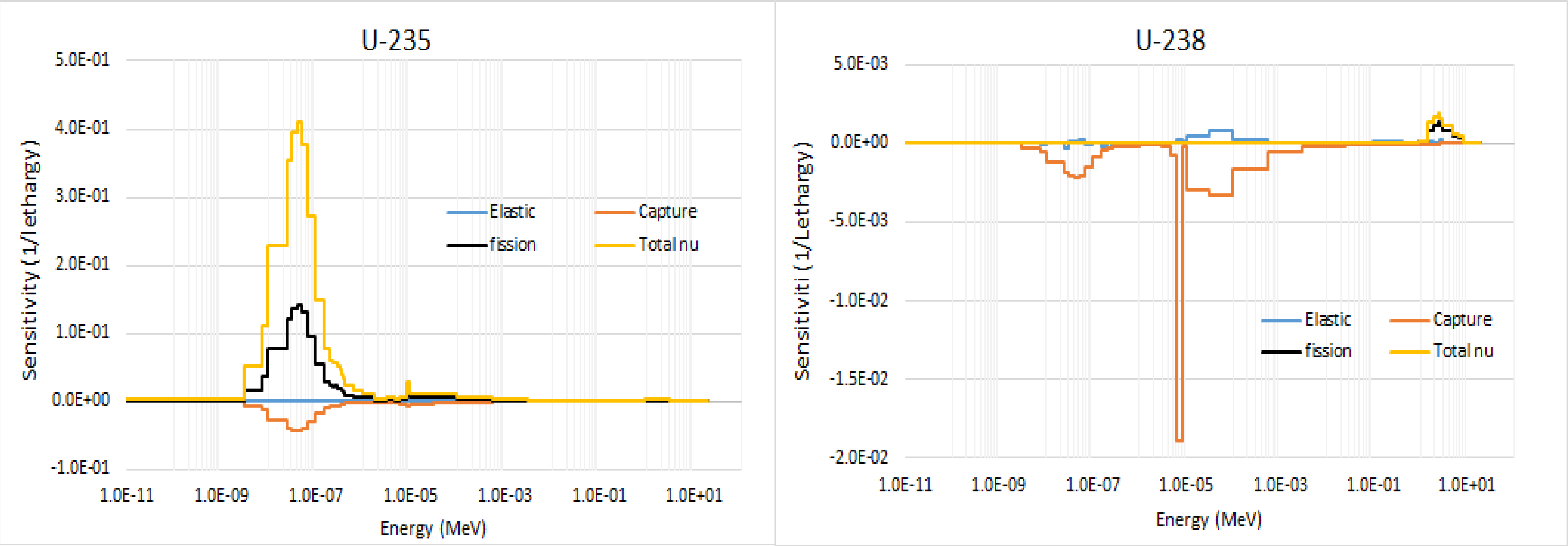


***Fig 7**: Energy dependent sensitivities of k_{eff} to U-235 and U-238 cross sections*

3. Result sensitivity and uncertainty of k_{eff}

Table 4: *The uncertainty of k_{eff} due to the uncertainty of the reaction cross-sections of some isotopes*

Isotopes	Reaction	Uncertainty	Isotopes	Reaction	Uncertainty
H-1	Capture	0.3094%	C-12	Elastic	0.0233%
H-1	Elastic	0.2384%	U-238	Capture	0.0221%
U-235	Fission	0.1641%	O-16	Elastic	0.0168%
Al-27	Capture	0.1373%	Be-9	Capture	0.0135%
Al-27	Elastic	0.1206%	Fe-56	Capture	0.0048%
Be-9	Elastic	0.0466%	U-238	Fission	0.0017%
U-235	Capture	0.0339%	Total reaction		0.4666%

3. Result sensitivity and uncertainty of k_{eff}

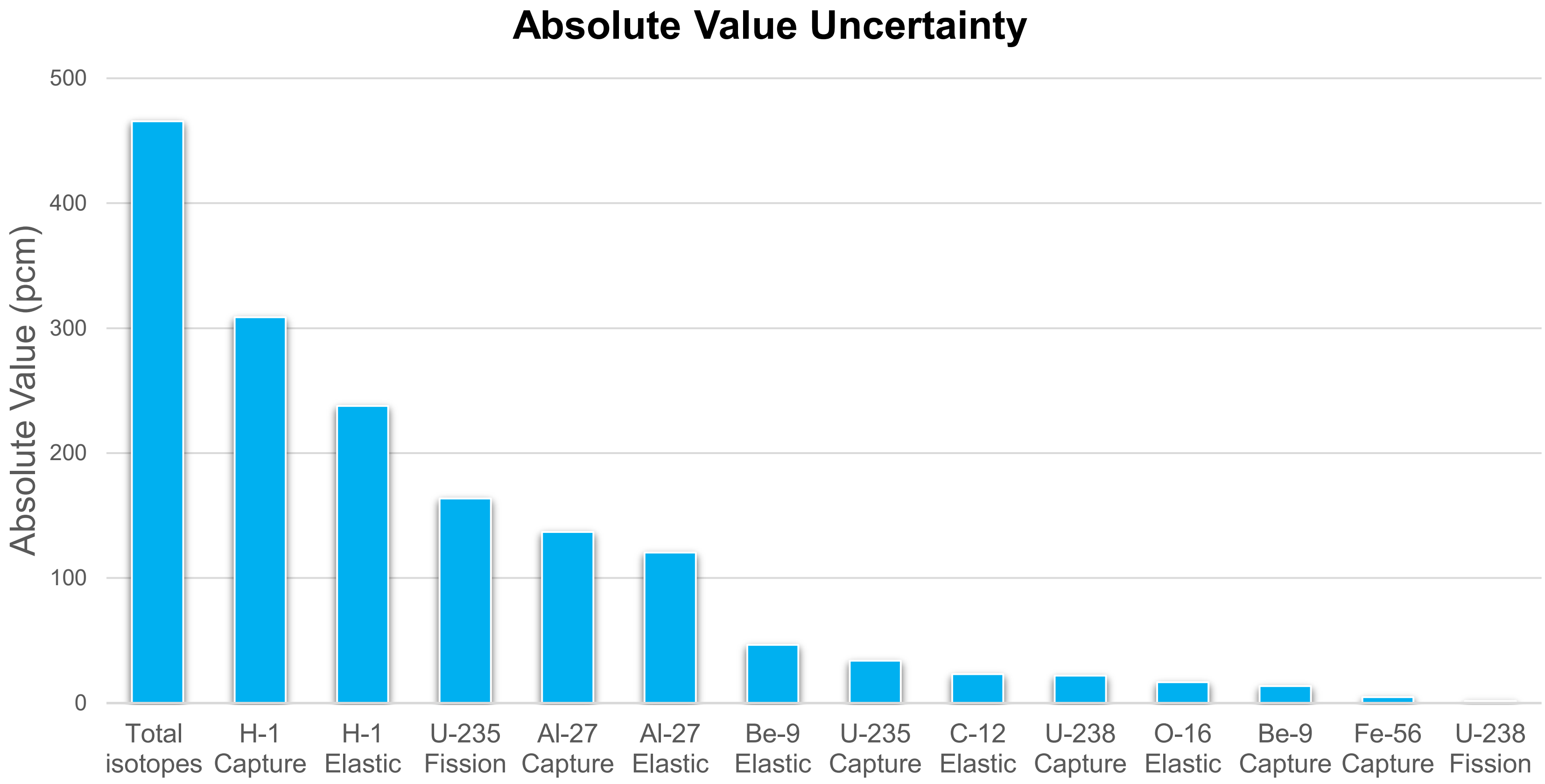


Fig 8: *The absolute value uncertainty of k_{eff} of the reaction cross-sections of some isotopes*

4. Conclusion

- The high positive sensitivities are found with the total ν and fission reaction of U-235, elastic scattering of H-1, C-12, B-9, Al-27, O-16.
- The largest negative sensitivities are from neutron captures of H-1, U-235, Al-27, U-238 or alpha production reaction of B-10.
- The maximum uncertainty due to the cross section error of H-1 from neutron capture and elastic scattering is 0.3094% and 0.2384%, respectively.

→ **Plan in the future work:** Extension of this analysis to the current operating core with LEU fuel.


Thank you for your attention!