Anisotropic scattering cross section treatment for reactor pressure vessel fast neutron fluence calculations

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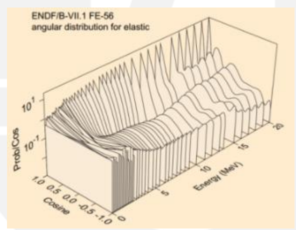
Introduction and Methods

RPV fast neutron fluence and S_N method

- An accurate calculation of the fast neutron fluence (E > 1.0 MeV or E>0.1MeV) at the RPV is necessary to estimate the structural integrity over the designed lifetime.
- S_N method simulation of the reactor pressure vessel fast neutron fluence obtains a high degree of confidence in the results.

Anisotropic scattering cross section

- Anisotropic scattering effect is severe in non-source region.
- Light nuclei and nuclei at high energies.



Primary component of RPV material: ^{56}Fe

Fast neutron fluence

✓ **The effect of anisotropic scattering on RPV fast neutron calculation should be considered.**

✓ **Different treatments for anisotropy scattering cross section will lead to different calculation results.**

Anisotropic Scattering Theory

- Differential scattering cross section: truncated Legendre series expansion.

$$\Sigma_s(\vec{r};E^{'}\rightarrow E,\vec{\Omega}^{'}\rightarrow\vec{\Omega})=\Sigma_s(\vec{r};E^{'}\rightarrow E,\mu_0)=\sum_{l=0}^{L}\frac{2l+1}{2}\Sigma_{s,l}(\vec{r};E^{'}\rightarrow E)P_l(\mu_0)$$

- If the scattering cross section is highly anisotropic, the Legendre expansion may result in negative regions in the interval.

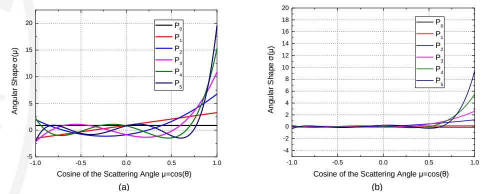
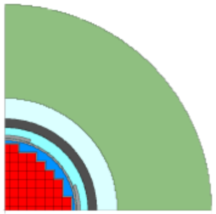


Fig.1. Differential scattering cross section within group 2 for ^{56}Fe (a) no transport correction; (b) BHS method

- Transport correction is employed to minimize the effect of the strong anisotropic scattering.

Horizontal cross section of AP1000 reactor



Results and Conclusions

■Different order of Legendre expansion

- The higher the Legendre expansion order is, the smaller the bias between different expansion orders will be.
- Different Legendre expansion order has bigger impact on neutron fluence which belongs to higher energy region.
- Different Legendre expansion orders provide a deviation within 10% versus reference P_5 solution at 1/4T in RPV.
- For expansion order L greater than 3, the bias is less than 4%.
- P_3 Legendre expansion order is already enough for RPV fast neutron fluence calculation and higher order is no need to employ.

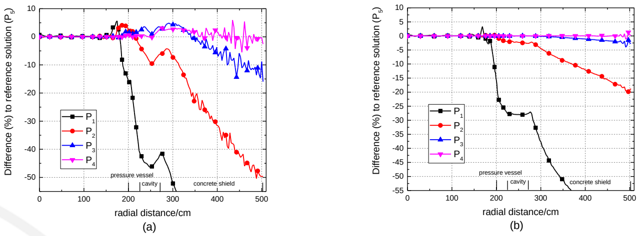


Fig.3 Radial profile of deviation between different Legendre expansion orders (0-deg azimuth): (a) Group 2; (b) Group 20.

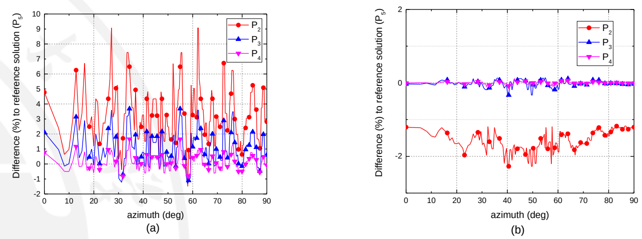


Fig.4 Deviation between different Legendre expansion orders on azimuthal flux distribution in RPV 1/4T: (a) Group 1; (b) Group 20.

■Effect of negative scattering source fixup

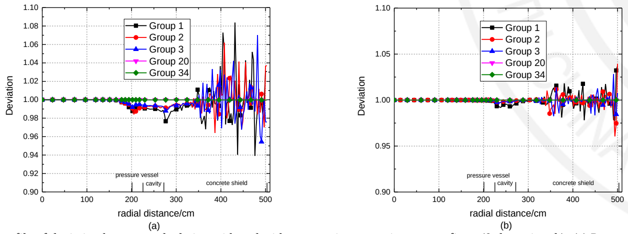


Fig.5 Radial profile of deviation between calculation with and without negative scattering source fixup (0-deg azimuth): (a) P_3 expansion; (b) P_5 expansion.

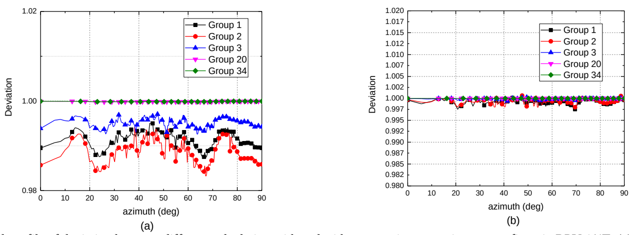


Fig.6 Azimuthal profile of deviation between different calculation with and without negative scattering source fixup in RPV 1/4T: (a) P3 expansion; (b) P5 expansion.

- With the increasing of the Legendre expansion order, the deviation decreases.
- The maximum bias can achieve to 2% for the first few groups and close to zero in other groups.
- Although the deviation of neutron fluence is small, with or without fixup may affect the convergence rate and even leads to no convergence. The negative scattering source fixup method is still need for calculation.

Results and Conclusions

■Adoption of transport correction method

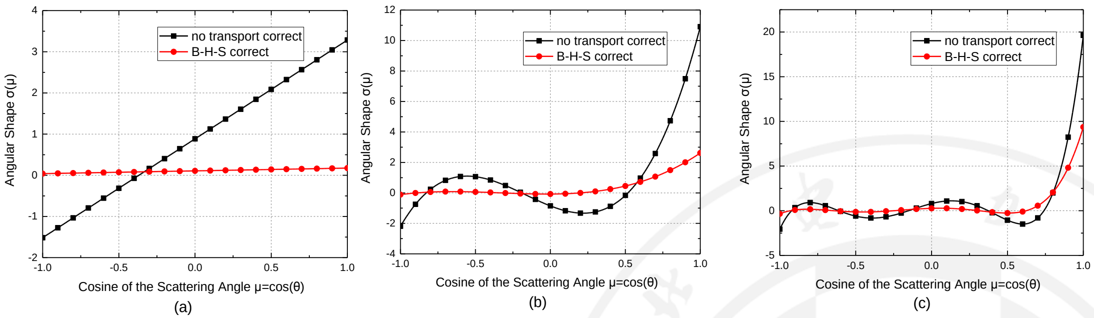


Fig.7 Angular shape of the cross section within group 2 for ^{56}Fe with or without BHS transport correction: (a) P_1 expansion

- **influence of transport correction**
  - Within group scattering cross section: smaller
  - Negative cross section: decrease.
  - The probability of neutron scattering to the direction that in addition to 0 to 60 degrees decreased.
  - Impact of different Legendre expansion orders: smaller.

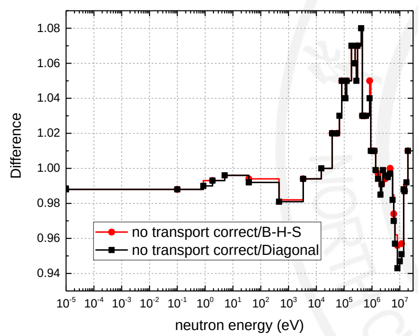


Fig.8 The deviation of neutron spectrum calculated by BHS or diagonal method (P_3, 30-deg azimuth)

- Whether to adopt transport correction has significant effect on RPV, the maximum bias can up to 10%.
- The calculation fluence difference between BHS method and diagonal method can achieve to 2%.

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THANK YOU FOR YOUR ATTENTION!