Impact of spallation neutrons on criticality

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Neutron spectrum in an accelerator driven sub critical system is different to the neutron spectra of thermal and fast reactors. The spallation neutron spectrum falls over a nuclear fuel in an ADS. Thus, for an arbitrary nuclear fuel, production and absorption cross sections of neutrons would vary with the incident neutron energy and the criticality coefficient, k_{eff} is expected to behave differently to a thermal or the fast reactor. For developing methods of estimation of k_{eff} in an ADS, let us assume that there is a cylindrical spallation target of dimension d x L = 20x50 cm^2 enclosed in side a fuel blanket of thickness X. The energy spectra of spallation neutrons produced in collision of 1GeV proton with a thick lead target is simulated using the CASCADE code [1] and the standard neutron spectra [2] of the thermal and a fast reactor have been used to estimate the spectrum average cross sections of different reactions occurring in different fuel elements such as ^{232}Th and ^{235}U of an arbitrarily assumed fuel system of an ADS. Spallation neutron spectrum spread up to several hundred MeV, may cause several reactions such as ^{232}Th (n,3n) (E_{th}= 11.61MeV),^{232}Th (n,3np) (E_{th}=18.82MeV) and ^{232}Th (n,8n) (E_{th}= 43.55MeV) etc. that were not possible in a critical reactor. The main problem arising because of spallation neutron spectrum is that in the energy range E_n>20MeV the experimental data is scarce and in this situation one has to depend on the calculations from the models or a deterministic code and a combination of a deterministic code and a Monte Carlo simulation code.

Thus, one can estimate k_{eff} from the knowledge of cross sections of all the production channels such as, i) single neutron type – (n,n´), (n,np), (n,nd), (n,nt), (n,nα) ,(n,nh) and (n,n2p) ii) multiple neutron type – (n, xn) where x = 2, 3…., (n, f), (n,2nh), (n,2nd), (n,2nt), (n,2npd), (n,2n2p), (n,3np), (n,3nd), (n,3nh), (n,3nt) and (n,3nα) and iii) neutron removal type – (n,γ) ,(n, p), (n, d), (n, t) and (n,α). The (n, f) reaction contributes in both production and the removal channels. Considering all the aforesaid reaction channels we have calculated [3] the k_{eff} for the three neutron spectra by using the following formulas and further details of the procedure will be published elsewhere. Let us assume I_0 is the incident neutron intensity falling on a material then the intensity of surviving neutrons after passing through x distance, $I_x=I_0\exp(-x\Sigma_t)$, here, Σ_t is the total macroscopic cross section of a neutron in the given material, Considering I_0 = 1 for a single neutron intensity, then the removal term, R of the neutron by way of all removal processes, (n ,γ), (n , p) and (n,2n) …… etc. may be written as,

$$R = (1-\exp(-x\Sigma_t))\,[(\Sigma(n,\gamma) + \Sigma(n,p) + \Sigma(n,d) + \ldots + \Sigma(n,np)+\Sigma(n,2n)+\ldots+\Sigma(n,9n)+\ldots+\Sigma(n,f) + \Sigma(n,2np)\ldots+\Sigma(n,3n\alpha)\ldots]/\Sigma_{tot} \quad (1)$$

and the remaining fraction, 1-R = L may be assumed to leak out from the fuel system.

Similarly, a production term, P may be written as follows,

$$P = (1-\exp(x\Sigma_t))\,[2\Sigma(n,2n)+3\Sigma(n,3n)+4\Sigma(n,4n)\ldots+9\Sigma(n,9n)\ldots+\langle\nu\rangle\Sigma(n,f) + 2\Sigma(n,2np)\ldots+3\Sigma(n,3n\alpha)+\ldots\ldots]/\Sigma_{tot} \quad (2)$$

Here $\langle \nu \rangle$= fission neutrons of a fuel element.

In the estimation of P, R and L contribution of the (n, n') channel is not included because of the obvious reasons. Thus,

$$k_{eff} = P/(R+L) \quad (3)$$

The elementary cross sections of different reactions up to 250 MeV neutron energy are calculated using the TALYS-1.0 code and for the energy 250 MeV the values of the cross sections are considered constant at the last value corresponding to 250MeV.This is a fair approximation because n-flux at E_n >250 MeV is very small.

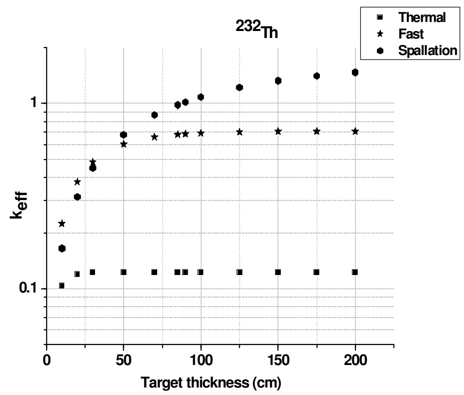

Fig.1a) Variation of k_{eff} with the target thickness for ^{232}Th target.

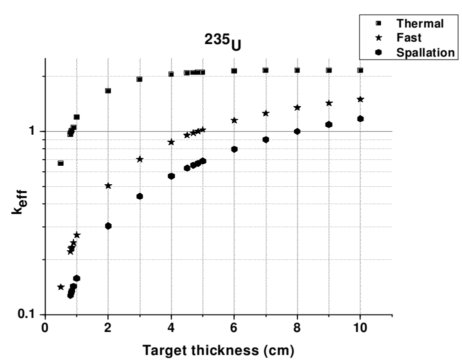

Fig.1b)Variation of k_{eff} with the target thickness for ^{235}U target.

From the data given in figs 1a) and b) we can infer that for the spallation spectrum k_{eff} is dominant in case of ^{232}Th while it is below the values corresponding to the thermal & fast spectra in case of ^{235}U. This shows that (n,xn) reaction play dominant role in case of fertile Th-fuel because of the presence of high energy neutrons compared to the fissile ^{235}U fuel. This kind of behavior was pointed out earlier in ref. [4] in a detailed study of (n,xn) reactions in fertile and fissile fuels.

We have compared results of our calculations with that estimated by Cullen et al. [5] and a good agreement is seen in the two calculations.

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References

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[5] D.E.Cullen et al. UCRL-TR-23310 (2007).