MULTINEUTRON EMISSION CROSS-SECTIONS OF Pb-208 AND Bi-209 FOR USE IN FUSION TECHNOLOGY

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ABSTRACT

Pb-208 and Bi-209 are considered as promising materials for fusion blankets because of their superior neutron multiplying characteristics. In this paper, emission cross-sections for neutrons, protons, alpha-particles and gamma-rays are investigated for these nuclides in the energy range 8-30 MeV using the framework of the multistep Hauser-Feshbach statistical theory combined with the Kalbach exciton model for the pre-equilibrium decay and the Brink - Axel model of the giant dipole resonance to account for the radiative capture competition.

Appropriate optical model potential parameters are selected to evaluate the compound nucleus reaction cross-sections at different neutron incident energies. (n,n'), (n,2n), (n,3n), (n,4n) and the total production cross-sections for neutrons, protons, alpha-particles and gamma-rays are inferred by performing consistent calculations.

I. INTRODUCTION

Pb-208 and Bi-209 are considered as promising materials for application in fusion blankets because of their superior neutron multiplying characteristics. Emission of charged particles from these nuclides is limited to the minimal because of their large Coulomb potential barriers. However, the generation of gamma rays may be the other important deciding characteristic to determine their suitability for fusion applications because of the radiation transport and shielding considerations. In this paper, all these factors have been examined by carrying out detailed cross-section calculations in the framework of the multistep Hauser-Feshbach statistical theory /1/, which includes Kalbach-exciton model /2/ to allow for the pre-equilibriuim decay and the Brink-Axel model /3/ of the giant depole resonance to account for the radiative capture competition. Geometry dependent hybrid model /4/ is also employed in the case of Bi-209 to bring out the limitations of these models in the data prediction. Discussion is limited to (n,2n), (n,3n), (n,4n), total neutron emission, total proton emission, total alpha-particle emission and total gamma-ray emission cross-sections in the energy range 8-30 MeV. Level density recipes used in the continuum energy region to compute the equilibrium-part of the reaction products include the improved Gilbert-Cameron option /5,6/ and the Ignatyuk-Smirenkin-Tishin option /7/ with the pairing and shell energy corrections taken from Cook et al /8/. In the pre-equilibrium reaction mechanism, Williams' formalism /9/ is employed for the computation of particle-hole state densities. Discrete energy levels with the parities, spins and gamma-ray branching ratios taken from the Nuclear Data Sheets are adopted for the target, composite and residual nuclides involved in the reaction decay chains. In the case of geometry dependent hybrid model which makes use of the Weisskopf-Ewing evaporation model /10/ to describe the equilibrium process, the level density parameter for the doubly or singly closed shell nuclides Pb-208 and Bi-209 is taken as A/20-A being the mass no. of the composite nuclide; pairing energy corrections as defined by Blann and Bisplinghoff /11/ are applied in the back shifted fashion and the energy dependent single particle level density is used for neutrons and protons.

II. MODEL COMPUTATIONS

The compound nucleus reaction cross - sections and transmission coefficients for neutrons, protons and alpha

- particles are calculated with the spherical optical model based code SCAT-2/12/. Multiparticle reaction cross-sections are computed with the GNASH code /13/ in the case of Hauser-Feshbach statistical theory and with ALICE91 code /14/ in the case of geometry dependent hybrid model. Neutron optical model potential parameters for Pb-208 and Bi-209 are taken from Cheema and Finlay /15/ and Bersillon /16/ respectively. Proton and alpha-particle optical model potential parameters of Perey /17/ and Huizenga and Igo /18/ are adopted. Gamma-ray strength functions are derived using the average s-wave resonance level spacings from Cook et al and the average gamma-ray level widths from Mughabghab and Garber /19/. Dipole resonance parameters are taken from Dietrich and Berman /20/ to account for the gamma-ray cascades in the calculations. The average reaction matrix constant to determine the exciton transition rates in the pre-equilibrium decay mode is fixed at 150 (MeV) cubed in the case of Kalbach exciton model.

III. RESULTS AND CONCLUSIONS

The computed (n,2n), (n,3n) and (n,4n) cross-sections for Bi-209 and Pb-208 are compared with the corresponding measured data /21,22/ in Figs.1 and 2. It is noted that in the case of Bi-209, the energy dependent IST level density option leads to a better reproduction of the measured (n,2n) and (n,3n) cross-sections compared to the often used GC level density option. However, GC option has an edge over the IST option in the case of doubly magic Pb-208. Since no (n,3n) data for Pb-208 and no (n,4n) data for both Pb-208 and Bi-209 are measured, this study serves to predict these data and also extrapolates the measured data beyond the energy range of their measurements. The predictions of the geometry dependent hybrid model shown in Fig.1 for Bi-209 are acceptable if quick estimates are desired with the accuracies in the range of 50% or so. It may be noted that the IST level density option reproduced the measured (n,2n) and (n,3n) crosssection data within 10% over a wide energy range of investigation. Based on this analysis, it may be concluded that the IST level density option represents the measured data better in these heavy nuclides.

Fig.3 depicts the total production cross-sections for neutrons, protons, alpha-particles and gamma-rays computed with the IST level density option for Pb-208 and Bi-209. It is noted that the total neutron emission cross-sections in both these nuclides are identical over the entire energy range. Proton and alpha emission cross-sections of Bi-209 are, however, higher than those of Pb-208 but their absolute magnitudes (<100 mb) are too low to play any significant role in nuclear safety or shielding considerations of fusion systems. Gamma emission cross-sections of Pb-208 are higher than those of Bi-209 over most of the investigated energy range and their magnitudes are high, of the order of

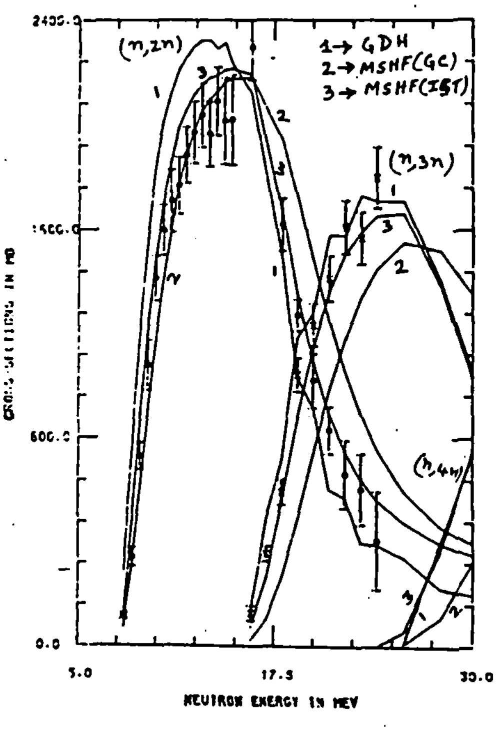

Fig.1 Neutron Emission X-Sections of Bi- 209 with IST and GC level densities.

several thousand millibarns. This aspect may be important in gamma transport and shielding evaluations. On this count, Bi-209 appears to be superior to Pb-208 for application in fusion blankets.

No explicit discussion of (n,n') reaction has been made in the text of this paper.It may, however, be mentioned that above the neutron incident energy of 14 MeV, both the GC and IST options yield similar data for (n,n') reaction ; but below 14 MeV, IST and GC predictions differ - range varying upto 25%.

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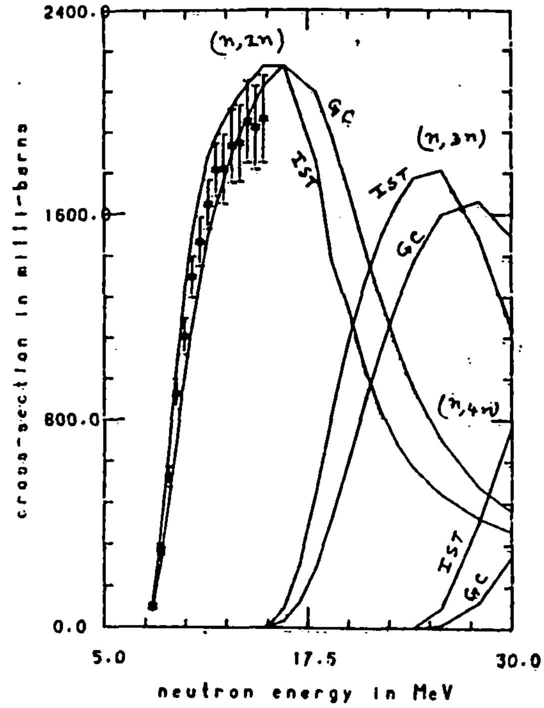

Fig.2 (n,2n),(n,3n),(n,4n) X-Sections of Pb-208 with IST and GC level densities.

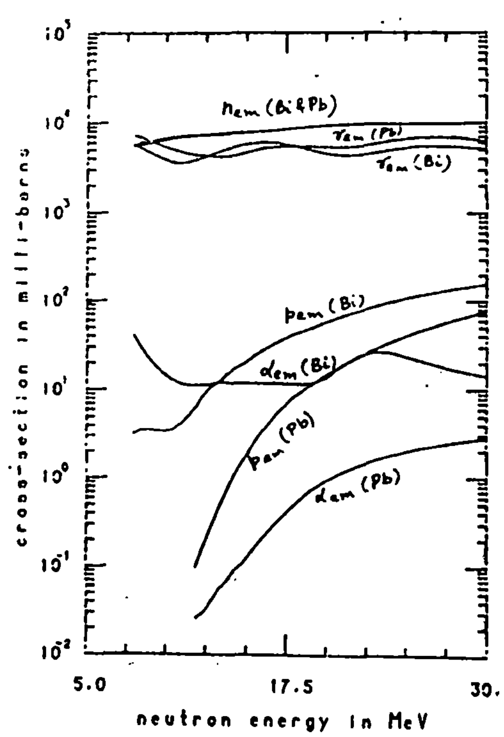

Fig.3 Particle Emission X-Sections with IST and GC level density options.