Spallation reaction with Tin isotopes

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Abstract. The calculations have been performed for the p+^{112,118,120,124}Sn systems at various energies namely, 0.66, 1.0, 3.65 and 8.1GeV. The predications of cumulative isotope production yield have been compared with the experimental data. The thick target calculation for lead and tin, which are the possible neutron spallation targets is done and a comparison is made for the quantities like Heat density and neutronic characteristics.

1. Introduction

Liquid Tin has been proposed as a possible coolant in the fast reactor systems and spallation target that exhibits many favourable properties and attractive features, in terms of high boiling point, low melting point, and low vapour pressure [1-2] . The heavy metal spallation targets become hot cell materials after long period of irradiation. The radioactivity is due to the spallation residues produced through reactions with various primary and secondary particles. The estimation of these products is very important due to production of some alpha emitting (^{146}Sm, ^{148}Gd, ^{150}Gd, ^{154}Dy, ^{210}Po etc.) toxic elements in heavy metal targets. In case of light targets like Sn these elements will not be produced but beta emitters will exist that have short half lives. The estimation of the radio-activity / toxicity is an important parameter to select the spallation/coolant material. The other advantage of Tin is that heat as well as neutron distribution is more spread over tin target volume compared to LBE. The neutron yield is 15-30% lower for the tin isotopes (^{112,118,120,124}Sn) compared to that from Pb and/or LBE. This suggests Tin as a possible target material to be studied. In this context, we have compared the residue production cross-section calculated with CASCADE.04 code [3-4] for the measured cross-sections for ^{112,118,120,124}Sn [5-6] at proton energies namely 0.66, 1.0, 3.65, and 8.1 GeV.

2. Method of Simulation

Monte Carlo program CASCADE.04 incorporates Intra-nuclear cascade – Pre-equilibrium - Evaporation/ Fission models to simulate spallation reaction mechanism for thin targets. Modeling details of intra-nuclear cascade, pre-equilibrium particle emission are described in detail in ref. [7-10]. The code has been subsequently modified for Evaporation/fission processes [3]. Algorithm of ionization loss is modified in our recent work [4]. Transport of low energy neutrons can be found in ref. [9]. The code uses experimental masses (AME2003) to calculate the Q values. The level density parameter is calculated based on Ignatyuk approach. Cross-sections of the hadron-nucleus collisions are calculated based on the compilations of the experimental data [11]. To calculate the nucleus-nucleus cross-sections we have used analytical approximations with parameters as defined in ref. [12]. The code uses 26-group constants [13] for neutron transport cross-sections below 10.5 MeV. In the present calculation, we have used particle evaporation only up to ^{4}He and higher mass particles are omitted to reduce computer time consumption.

3. Residue production cross-section for p+^{112,124}Sn systems

We have compared the calculated yield of these nuclei using CASCADE.04 with the experimental data at energies namely 0.66, 1.0, 3.65, and 8.1 GeV. The mass yield is plotted in *FIG.1* where it is seen that the distribution widens with energy due to opening of more channels. The isotope production is shown in *FIG.2* and *FIG.3* for ^{112}Sn and ^{124}Sn at 3.65GeV, respectively. The predictive power of the code for different isotopes of Sn appears to be very good.

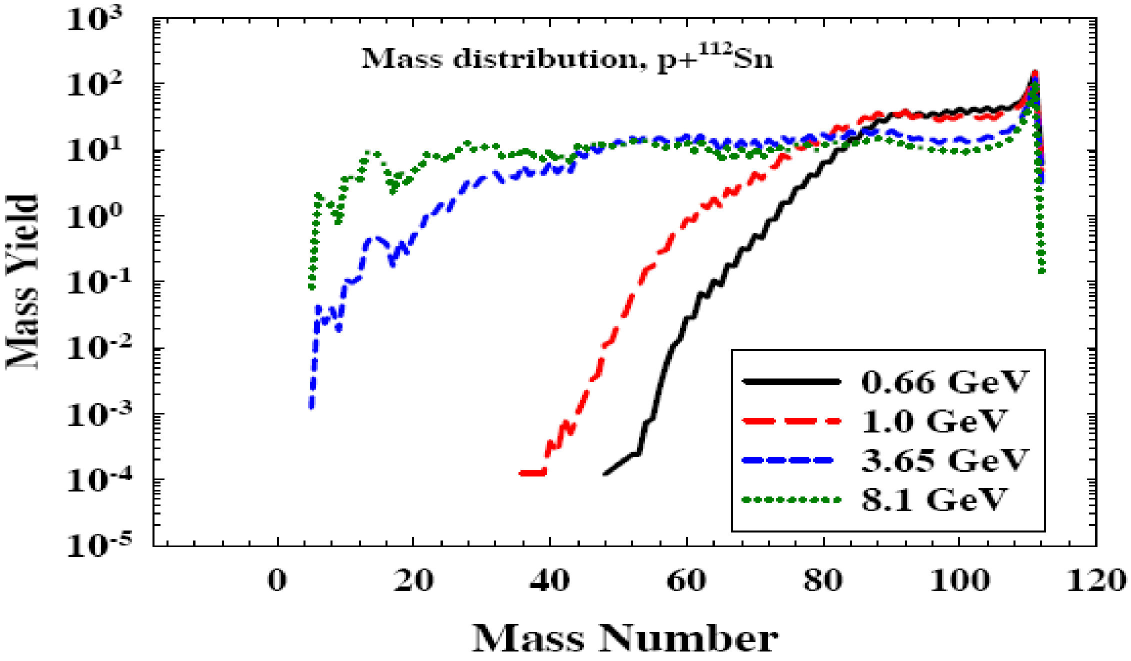

FIG. 1 The mass distribution at energies namely 0.66, 1.0, 3.65, and 8.1GeV is shown where the spread with energy reveals opening of more processes/channels at high energies.

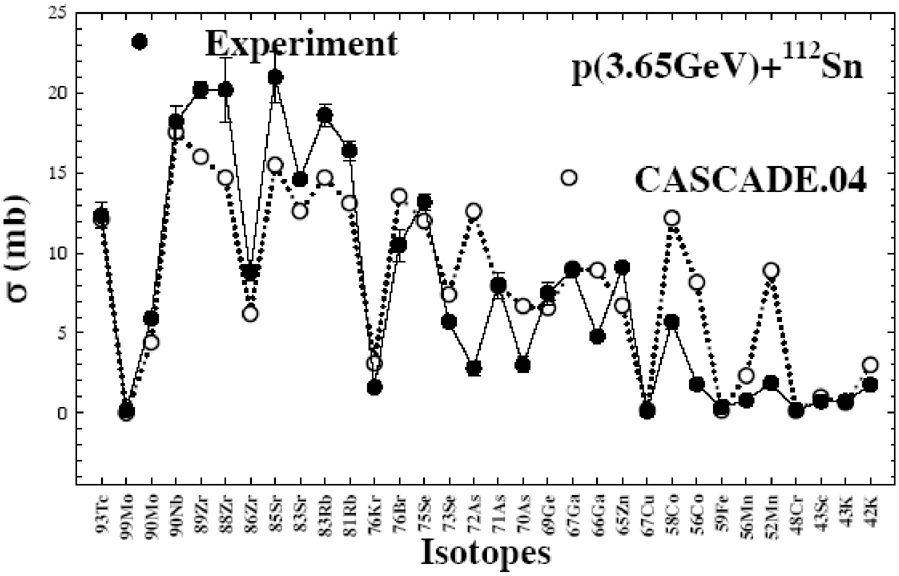

FIG.2 Cumulative yield of the residues from P(3.65GeV)+^{112}Sn target. The calculations are done using CASCADE.04 code and experimental data are taken from ref. [5-6].

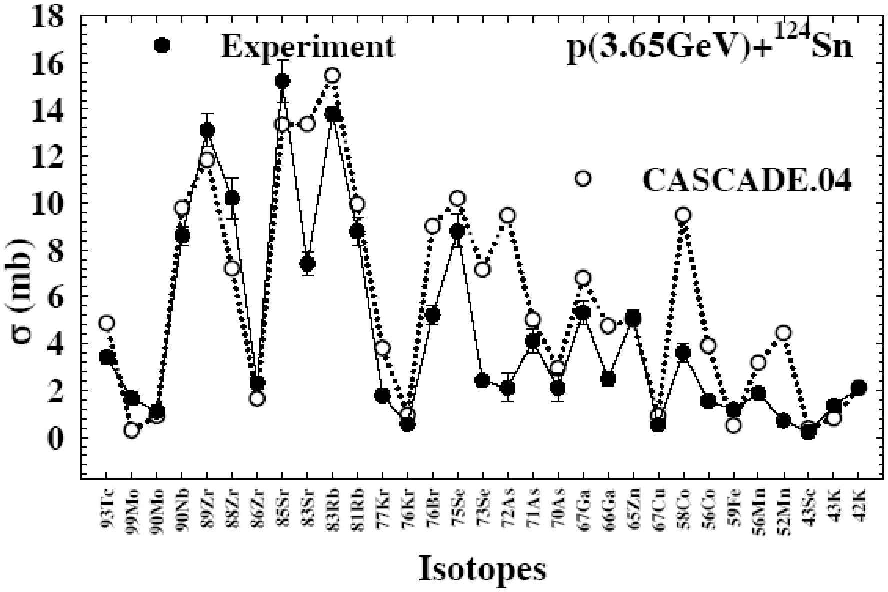

FIG.3 Cumulative yield of the residues from P(3.65GeV)+^{124}Sn target. The calculations are done using CASCADE.04 code and experimental data are taken from ref. [5-6].

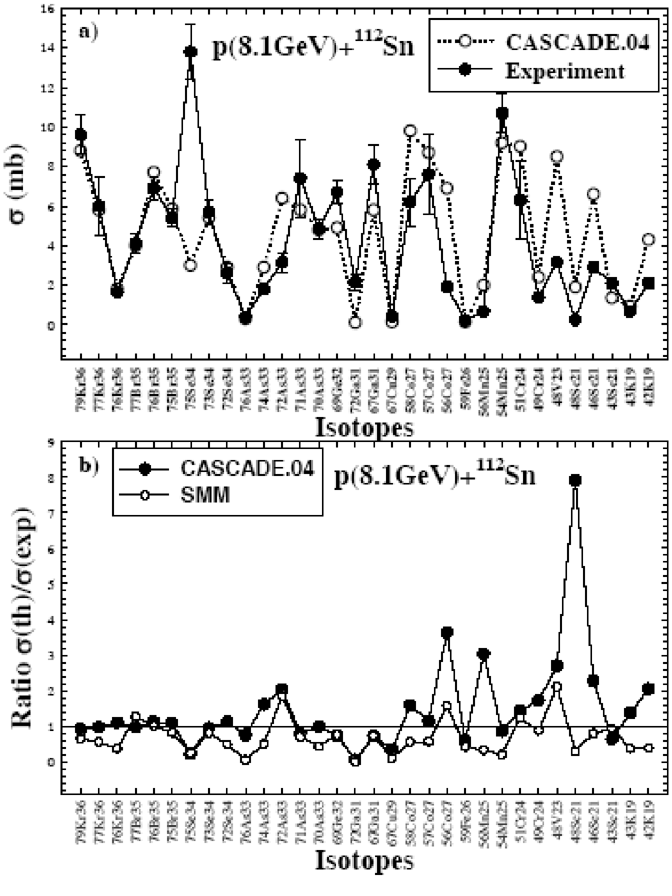

FIG. 4 a) Cumulative yield of the residues from P(8.1GeV)+^{112}Sn system. b) Ratio of calculated and experimental data is also plotted.

The isotope production for ^{112}Sn at 8.1GeV is shown in *FIG.4*. It is observed that the code takes care of the energy dependence well and data are in agreement with the calculated values at both the energies. The data were also compared with the values calculated with SMM [14] which is INC+statistical multifragmentation model. It is observed that the CASCADE.04 predictions are consistent with the data well for the Tin isotopes at different energies. There are a few discrepancies e.g. for ^{48}Sc, ^{58}Co, ^{75}Se nuclei. The excitation function for ^{69}Ge production as given in Fig 5 shows that the experimental trend is well reproduced by the theory.

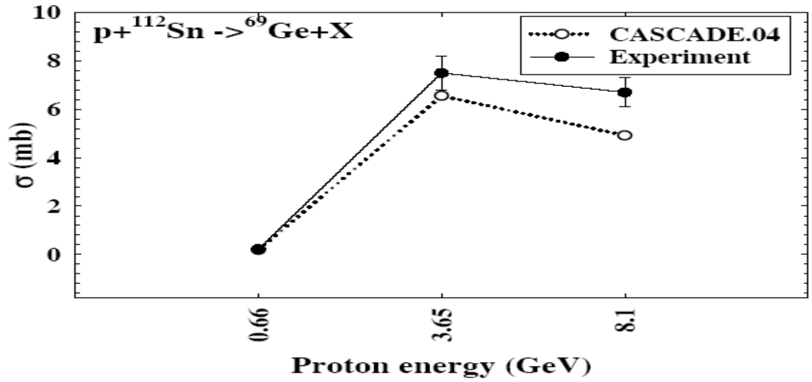

FIG.5 The production cross-section for ^{69}Ge at various energies is plotted.

4. Neutronic characteristics and heat distribution in Sn and LBE

The neutron yield is estimated for Tin and LBE at 1.0 GeV proton beam and cylinder target (Length=100cm, Dia.=40cm). The beam was assumed to be Gaussian of FWHM=2.35cm entering through a hollow pipe of diameter 10cm and hitting 20cm inside the target volume. It was found that yield from Tin is 15-30% lower compared to LBE as given in figure 6.

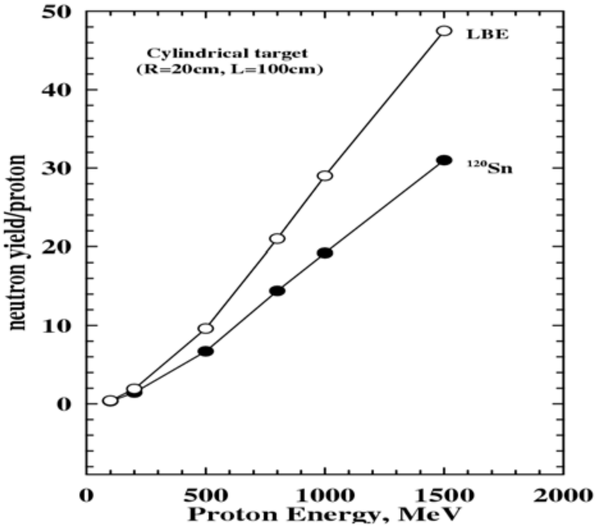

FIG.6 Neutron yield for LBE and ^{120}Sn target

The neutron yield along the target length (see fig. 7) is the maximum at around 10-12 cm from the beam hitting position. The ratio of max. to min. neutron number is one order of magnitude for LBE which will cause similar heat deposition pattern in the reactor and this ratio is two times less for the Tin.

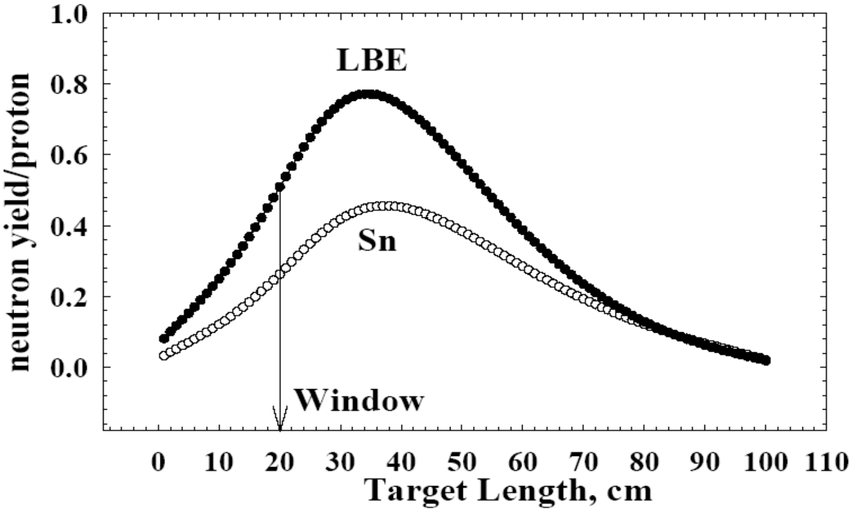

FIG.7 Neutron yield per cm along the target length for LBE and ^{120}Sn target at 1.0GeV proton energy.

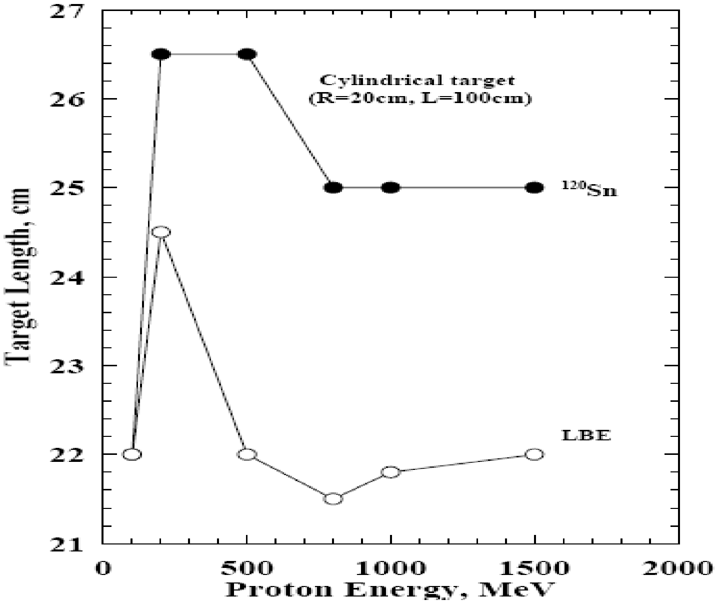

FIG.8 Position of the maximum heat deposition in LBE and Sn at different energies.

Window, which couples the accelerator vacuum to the target, is an important component and it needs to be cooled as maximum heat deposition takes place near this region. This maximum heat deposition (see Fig. 8) is further away at around 2cm for the Tin target compared to LBE which creates less temperature in the window. The maximum heat density comes out to be 537 and 675 watt/cm^3/mA for Tin and LBE (see fig. 9-10), respectively, also that the heat is more distributed over the target volume in Tin due to higher penetration power of the incident proton beam when compared to LBE.

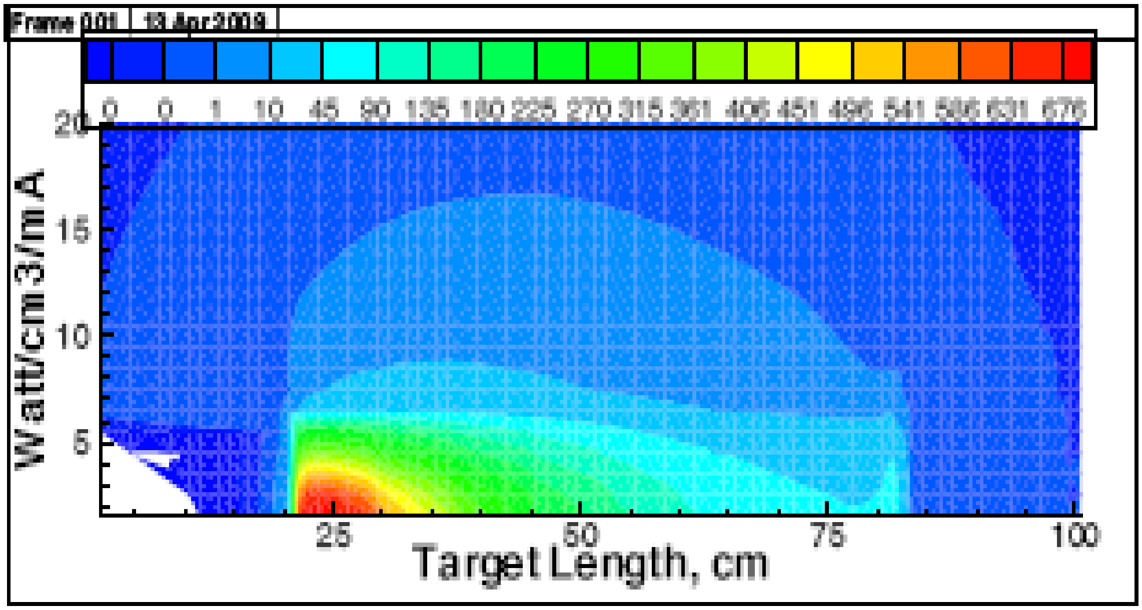

FIG. 9 Heat density distribution for the cylindrical LBE target (L=100cm, Dia.=40cm).

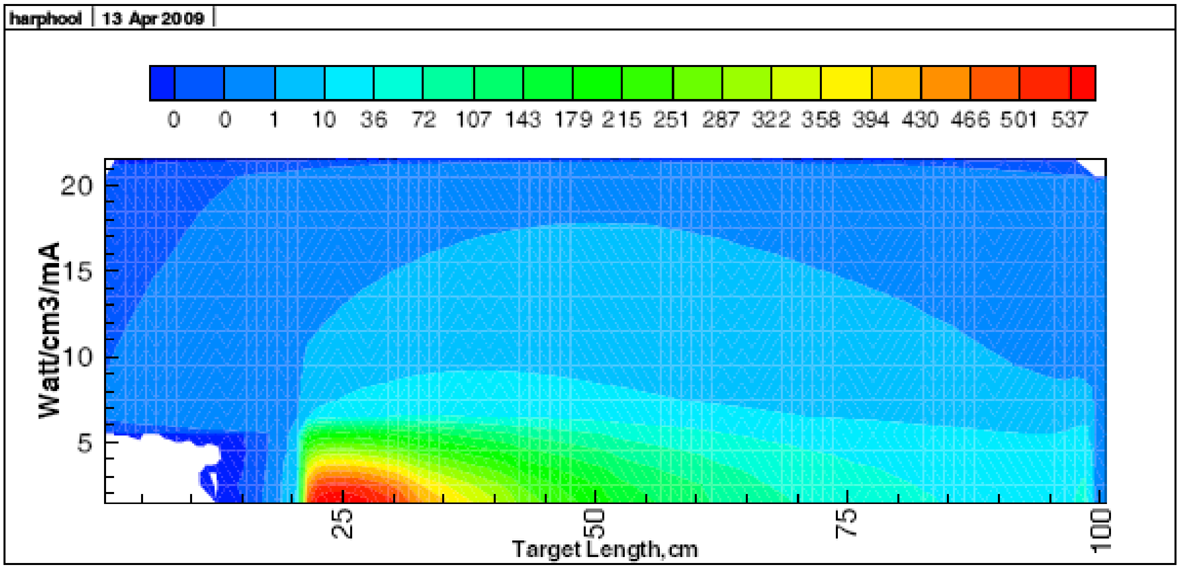

FIG. 10 Heat density distribution for the cylindrical natural Tin target (L=100cm, Dia.=40cm).

Discussion and Conclusions

The prediction power of CASCADE.04 code is good enough for the estimation of the cumulative/independent yield of spallation production over of a range of energies and mass number. The code takes care of target isotopic effect as seen in the case of $^{112-124}$Sn systems. Tin as a spallation and coolant material, seems to be promising as there will be no rare earth and Po related alpha activities, has good thermal properties and neutronic characteristics. The heat and neutron distributions are more spread over the target volume in the tin target compared to Heavy target like LBE. The power peaking due to spatial spallation neutron coupling to the reactor is prominent in LBE because of high neutron gradient along the target length. Other issues like corrosion, erosion, DPA etc have to be studiedfor Tin to evaluate its ultimate usefulness as a coolant or spallation target in various systems.

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