CHAPTER VII

FISSION AND SHORT RANGE OR SPALLATION HYPERFRAGMENTS

7.1 INTRODUCTION :

In the fission process a nucleus after interacting with a projectile breaks up into two or more fragments of comparable masses as discussed in previous chapters. Generally disintegrating nuclei during high energy interactions emit various numbers of nucleons singly or in clusters leaving a residual target nucleus, that recoils. The name used is 'spallation[1]' to describe this type of reaction. The spallation may be produced almost in all nuclei excluding the lightest ones by using different projectile with energies of several million electron volts. However, the spallation reaction[2] would require a threshold value of excitation energy of about 110 Mev for medium weight nuclei, whereas the fission process would require a threshold of about 50 Mev only. Of this 50 Mev, about 30 Mev is needed for the excitation energy to enable the fission fragments to cross over the potential barrier and the reminder accounts for the mass difference between the fissioning nucleus and the products. Again it may be pointed out that the fission events studied here are the results of splitting of the residual excited nuclei in a spallation reaction.

The mechanism that fits the fission and spallation can be explained on the basis of cascade evaporation[3] model as discussed in Chapter III. When cascade stage is over in about 10^{-22} seconds or so, the nucleus is left to a highly excited stage and the energy is distributed throughout the nucleus in about 10^{-14} seconds. At this stage, several nucleons or cluster of nucleons are boiled off from the excited nucleus in the process of de-excitation which may simulate the evaporation from a liquid drop. Thus, this results in the spallation process. Alternatively and simulteneously, after liberating a few nucleons, the excited nucleus may split into two parts in various ways thus undergoing fission. Seaborg[4] et al, however, argued that at higher excitation energy, the greater will be the number of particles which will be evaporated and longer the time required for nuclear disintegration. Thus longer the time the greater will be the probability that the excited nucleus will be able to organise itself into a fission mode of oscillation.

However, at high energy nuclear interaction at about 300 Mev, the spallation exhibits the new kinds of reaction in which new kinds of particles begining with π-meson emerge. At still higher energy say at 500 Mev or above, whole family of particles called 'strange particles' (μ-mesons and hyperons) make their gradual appearance with increasing energies. At still higher energy, say, at about 6 Bev, the antinucleons are produced. These strange particles have strange behaviour so far their production and decay processes are concerned. According to the strangeness theory advanced by Gell-mann[5] and also by Nishijima[6] the strange particles can not be produced singly in nuclear collisions but must be produced in association with other strange particles in order to conserve the strangeness quantum number applicable for these strong interactions. However, during decay which is a weak process the particles donot require such conservation to be obyed.

Now, for the strange particle k^- when it interacts with a nucleus, it is believed to undergo one of the following reactions.

$$k^- + p \longrightarrow \Lambda^0 + K.E$$

$$\Lambda^0 + \pi^0$$

$$\Lambda^0 + \pi^+ + \pi^-$$

and

$$k^- + \eta \longrightarrow \Lambda^0 + \pi^-$$

$$\Lambda^0 + \pi^- + \pi^0$$

Thus in the strong interaction of a particle with a nucleus, mesons and hyperons may be produced along with a number of nuclear fragments of various charges and masses. A Λ^0-hyperon so produced may be emitted (a) directly singly, (b) picked up by a nuclear fragment emitted during the interaction and thus forming hyper fragment. In this the Λ^0 hyperon must be bound to the fragment and must have with the same velocity as that of the fragment which finally disintegrates because of its inherent in-stability, or (c) may undergo collisions with the nucleons inside the nucleus and is slowed down. This slowing down Λ^0 -hyperon may bind itself with some other nucleons of the target nucleus and may be evaporated as hyper-fragments, (d) or it may not be able to come out of the nucleus and thus forming a Crypto-fragment, (e) or it may remain bound to the residual nucleus that recoils as a spallation hyper-fragments. It may however be mentioned that because of strangeness conservation, the production of HFS in interaction of strange particles like k^- is more frequent (about ten times) then that in the interactions of nucleons or anti-nucleons. The existence of hyper fragments was first inferred by Polish scientists M.Danysy[7] and Pinewiki in the year 1953, from the study of the tracks in emulsion exposed to cosmic rays. A micro-photograph of the event is shown in the plate No. 2. Since than a large number of worker[8-11] have found from the study of hyper fragments production, that majority of short range hyper fragments are the heavy spallation products of silver and bromine nuclei. From their observations they interpreted that the spallation hyper fragments have masses ranging from 60 to 90 and they are confined within the range $r \leqslant 5$ microns. The events having inter-connecting tracks of ranges greater than 5 microns were interpreted as light hyper fragments having mass 20 mp.

Here, in the present study, an attempt has been made to compare the data obtained from studies of fission and these of short range spallation hyper fragments on the basis that the contribution of different stages of de-excitation to both the process may be similar. It is interesting to note that although fission events are assumed to be produced mainly towards the last stages of evaporation of de-excited nuclei, yet it is expected that there may be some contribution from the cascade stage also. Because in the case of production of spallation hyper fragments there is a definite contribution from the cascade process. The spallation fragments are comparatively heavy (A > 40). They give rise to emission of short range hyper fragments (R < 20 microns). Hence a comparative study of these two types may give clue to the stages of production of fission.

7.2 EXPERIMENTAL PROCEDURE AND SELECTION CRITERIA :

Because of the high rate of production of hyperfragments the K5 emulsion stack exposed to 1.8 Gev/c K^- beam has been used for our present study. Preliminary area scanning was done under low magnification (X15) to record all the disintegration stars with $N_h \geqslant 8$. The star with lower N_h value is excluded to ensure the inclusion of Ag and Br disintegrations only. The stars so obtained was then carefully examined under high magnification (2000X oil immersion objective) to collect (i) the disintegration stars with two short tracks (binary fission events) and also (ii) for any possible short range double stars. The selection criteria adopted for binary fission events have already been discussed in Chapter V. However, a double star constituting the 'Goks' is difficult to accept as short range hyperfragments without doubts. No doubt, it may represent a genuine short range hyperfragments, but one can not rule out the possibility that such a double star may be attributed to one of the following causes,

(i) Chance coincidence,

(ii) Capture of negative particles (π^-, k^- or Σ^-),

(iii) Interaction in flight (collision).

To eliminate the above background events, attempts have been made in the following way. All double stars are scrutinised under high magnification, so that the possibility of coincidence is negligible. k^- and Σ^- stars are generally of long ranges. Silverstein[12] from an observation of twenty k^- and Σ^- star in G5 emulsion found that this k^- and Σ^- had ranges greater than 450 microns. Therefore the contamination due to these capture events is negligible. The background events due to π^- capture are also inappreciable.[13] There may be some collisions events but one should not expect a large increase in the number with a decrease in length of the connecting track. One may conclude therefore that the contribution from capture of negative particles will be small and contribution from the collision events will also be not very large. On these considerations about 70 p.c. of short range double stars will be genuine hyperfragments. The stars (Crypto fragments) for which the distance of separation (<2 microns) can not be measured have been avoided for the present analysis.

They are termed as Non-separable double stars (N.D.S.). They have only been considered for the calculation of frequency.

7.3 RESULTS :

A total of 30,000 stars were scrutinised and a number of 225 genuine binary events and 150 hyperfragments were collected for the present study. A prong multiplicity of spallation hyperfragments is shown in the figure 7.1. From the observed distribution of the heavily ionising prongs, the average value of N_h is found to be $\sim$ 13 $\pm$ 0.21. The mean excitation energy corresponding to the average N_h values have been estimated to be 420 Mev. The charge of the hyper-fragment has been estimated from the observation and identification of the heavily ionising tracks emitted from the primary disintegration as done in case of binary fission. The charges so estimated are represented in the fig. 7.2. From the observed distribution, the charges of hyper-fragments are found to vary from 24 to 34 and the masses from 48 to 68 protonic masses. Hence the average charge and mass as obtained from the distribution may be taken to be 28 and 56 respectively. From the range distribution as shown in the figure 7.3 the ranges of spallation hyperfragments are found to vary from 2.5 microns to about 13 microns, but the maximum number lies within the value of 2.5 to 5 microns. The angular distribution of spallation hyperfragments with respect to primary beam direction is found to be anisotropic as shown in the fig. 7.4. The forward and backward rating is 2.5 $\pm$ 0.15. The observed

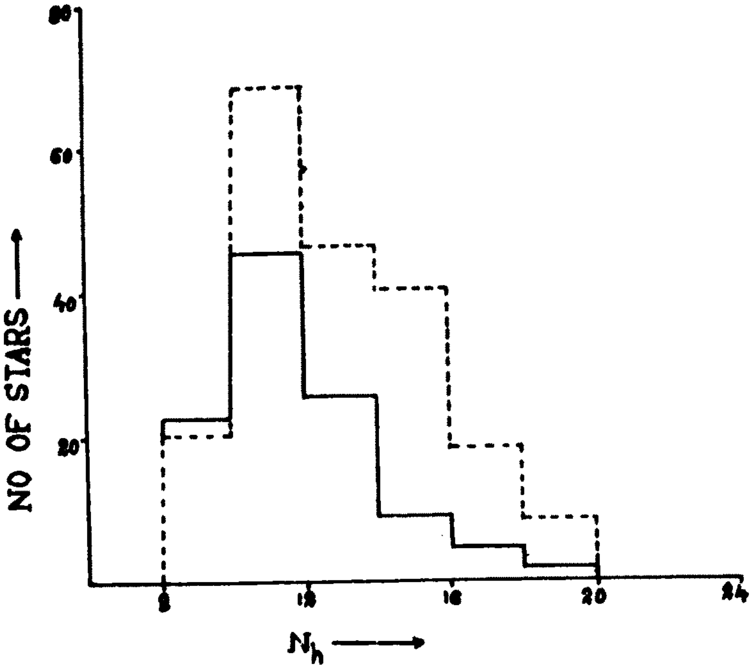

Fig 7.1 N_h DISTRIBUTION OF SPALLATION HYPERFRAGMENTS COMPARED TO N_h DISTRIBUTION OF FISSION EVENTS

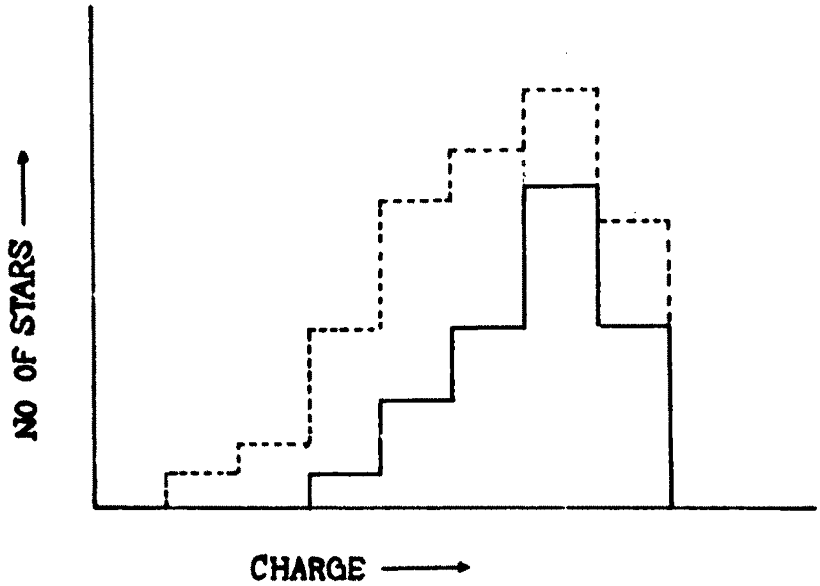

Fig 7.2 CHARGE DISTRIBUTION OF SPALLATION HYPERFRAGMENTS COMPARED TO CHARGE DISTRIBUTION OF FISSION EVENTS.

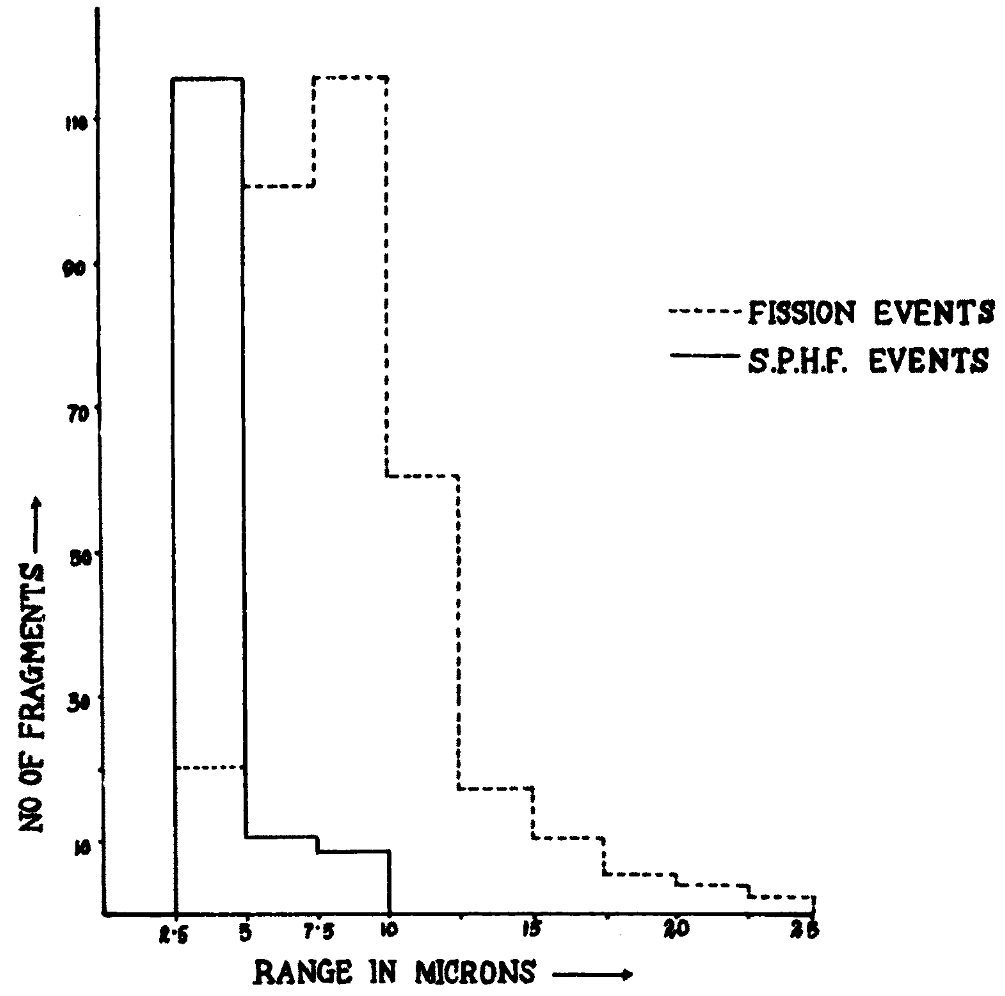

Fig 7.3 RANGE DISTRIBUTION OF SPALLATION HYPER-FRAGMENTS COMPARED TO RANGE DISSTRIBUTION OF FISSION EVENTS.

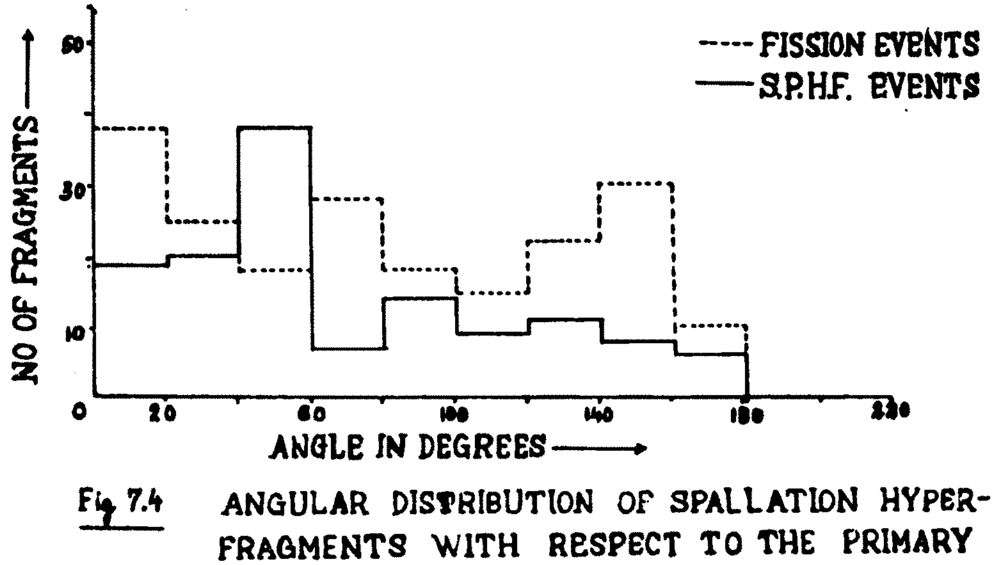

Fig 7.4 ANGULAR DISTRIBUTION OF SPALLATION HYPER-FRAGMENTS WITH RESPECT TO THE PRIMARY BEAM DIRECTION COMPARED TO ANGULAR DISTRIBUTION OF BINARY FISSION BISECTOR WITH RESPECT TO PRIMARY.

anisotropy indicates that a large number of the spallation hyperfragments are also of cascade origin.

7.4 COMPARISION OF RESULTS AND DISCUSSIONS :

Spallation hyperfragment studies reveal some interesting results. It is observed that the different aspect of spallation hyperfragments have close similarity with that of the fission events. Table below reflects some of the similar observations for both the types of events for k^- interaction in nuclear K5 emulsion.

Table 7.1

Comparision of data obtained from SPHF and fission (Binary)

Observation	Excitation energy in Mev	Frequency per 100 interactions	Ranges in microns (peak value	Charge distribution (Z)	Mass distribution (A)	F/B ratio
Fissions	~420	0.008	10	20-34	40-68	1.40±0.08
Spallation hyperfragment	~420	0.005	5	24-34	48-68	2.5 ±0.15