Branching factors on the s-process path

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To calculate the fraction of the s-process flux branching off the main s-process path at a given branching point a "branching factor" is defined as:

$$f_{branch} = \frac{p_{branch}}{p_{branch} + p_{main}},$$

where p_{branch} and p_{main} are the probabilities per unit time associated to the nuclear reactions suffered by the branching point nucleus and leading onto the branch or onto the main path of the s process, respectively.

There are several types of branching points: in the "classical" case p_{main} corresponds to λ, and and p_{branch} corresponds to p_n:

λ is the probability per unit time (hereafter: second) of the unstable isotope to decay:

$$\lambda = 1/\tau = ln2/T_{1/2}$$

where τ is the mean lifetime, i.e., the time is takes for the abundance of an unstable nucleus to become $1/e$ of the initial, and $T_{1/2}$ is the half life, i.e., the time it takes for the abundance of an unstable nucleus to become 1/2 of the initial, $\tau = T_{1/2}/ln2$ (ln 2 = 0.693)
($http://en.wikipedia.org/wiki/Exponential\_decay$)

p_n is the probability per unit time (hereafter second) of the unstable isotope to capture a neutron:

$$p_n = < \sigma v > N_n,$$

where N_n is the neutron density in neutrons/cm^3 and $< \sigma v >$ is the Maxwellian averaged product of the relative velocity v and the neutron capture cross section σ (see lecture 3). σ is usually given at an energy of 30 keV, corresponding to a temperature of 348 MK, and in unit of mbarn, corresponding to 10^{-27} cm^2. $< \sigma v >$ can be approximated to $\sigma \times v_{thermal}$, where $v_{thermal}$ is the thermal velocity $= \sqrt{2k_BT/m}$, with k_B = Boltzmann constant = 8.6×10^{-5} eV/K, m = mass of the neutron = 939 MeV/(speed of light)^2, T=temperature in K. If k_BT=30 keV, then $v_{thermal} = 2.4 \times 10^8$ cm/s.

A typical example of this "classic" case is the isotope ^{95}Zr, which has a half life of 64 days, and can capture neutrons and produce the "r-only" isotope ^{96}Zr even during the s process. When the branching point is a long-living, or even stable isotope, but its β-decay rate increases with the temperature, the opposite applies: p_{branch}=λ and p_{main}=p_n. In even more complex situations, a radioactive isotope may suffer both β^+ and β^- decays, as well as neutron captures. In this case, three terms must be considered at denominators in the definition of the branching factor above: p_n, and λ for both β^+ and β^- decays.