Abstract. $R$-process yields for a helium layer have been calculated within a network of 6033 heavy nuclei using a steady flow approximation. The calculation of the neutron capture cross sections has been improved. The beta decay rates computed by Klapdor and his colleagues have been used in the calculation. We find that the $r$-process yield peaks near mass numbers 80 and 130 require a neutron number density of approximately $10^{20}$ cm$^{-3}$ and a freezing time comparable to or less than 0.1 s. The peak near mass number 195 requires a neutron number density of about $10^{21}$ cm$^{-3}$ and a freezing time comparable to or less than about 0.01 s. The individual yield features of the steady flow $r$-process depend entirely upon the neutron capture cross sections of the nuclei along the flow path and the beta decay rates, which can shift the flow path and thereby introduce inappropriate capture cross sections into the determination of the yields.

1. Introduction

During the last few years much attention has focussed on helium layers as possible sites of the $r$-process, either in supernova explosions or in helium core flashes (Truran et al., 1978a, b; Cowan et al., 1980, 1982a, b; Hillebrandt and Thielemann, 1977; Thielemann et al., 1979; Klapdor et al., 1981; Hillebrandt et al., 1981; Blake et al., 1981). In these studies the general practice has been to consider an evolving astrophysical scenario and to attempt to determine how the $r$-process may operate in that scenario. In the present study we consider a steady flow approximation to the $r$-process which is very simple to calculate and which allows us to experiment with the physical quantities in order to determine the sensitivities of the $r$-process yields to some of these quantities. We have explored these sensitivities for the range of conditions that may be appropriate for the $r$-process in a helium layer.

In the next section we discuss the meaning of a steady flow $r$-process. In the following two sections we discuss the nuclear input data to the calculations. We then go into the numerical experiments and their interpretation.
2. The Steady Flow R-Process

The r-process network used in this study is the heavy nuclei part of the combined network used in previous studies by Trurán et al. (1978a, b) omitting the light element network which includes charged particle reactions. In the heavy nuclei network the possible reactions include neutron capture, photodisintegration with emission of neutrons, and beta decay with the emission of 0, 1, 2, or 3 neutrons from the product nucleus, depending upon the degree of excitation of that nucleus following beta decay. The network contains 6033 nuclei and ranges in neutron number from the valley of beta stability to the neutron drip line. In proton number it ranges from 14 to 114.

Consider a steady rate of input of nuclei to the bottom of the network at $^{28}\text{Si}$. If one waits for a long time, neglects fission recycling, and lets nuclei flow out at the top of the network, then all nuclei in the network will approach a steady state abundance in which the rate of inflow of nuclei is equal to the rate of outflow of nuclei. This is the steady flow approximation that we seek.

In the following expression the left-hand side represents the inflow of nuclei and the right-hand side represents the outflow of nuclei:

$$
\langle \sigma v(Z_{-1}, A) \rangle N(Z, A - 1)N_n + \lambda_{\gamma}(Z, A + 1)N(Z, A + 1) + \\
\lambda_{\gamma 0}(Z - 1, A)N(Z - 1, A) + \lambda_{\gamma 1}(Z - 1, A + 1)N(Z - 1, A + 1) + \\
\lambda_{\gamma 2}(Z - 1, A + 2)N(Z - 1, A + 2) + \lambda_{\gamma 3}(Z - 1, A + 3)N(Z - 1, A + 3) = \\
\langle \sigma v(Z, A) \rangle N(Z, A)N_n + \lambda_{\gamma}(Z, A)N(Z, A) + \\
[\lambda_{\gamma 0}(Z, A) + \lambda_{\gamma 1}(Z, A) + \lambda_{\gamma 2}(Z, A) + \lambda_{\gamma 3}(Z, A)]N(Z, A),
$$

(1)

where $\sigma$ is a neutron capture cross section and $v$ is a neutron velocity, and their product is a piece of input data; $\lambda_{\gamma}$ is a photodisintegration rate and $\lambda_{\gamma}$ is a beta decay rate with the emission of the number of neutrons given in the second subscript. All of these quantities are functions of the charge and mass numbers. $N$ is the number of the indicated nucleus and $N_n$ is the number density of neutrons.

Equation (1) may be applied to all the nuclei in the network, whereupon it is possible to solve for the ratio of each nuclear abundance to that of $^{28}\text{Si}$, and the abundance of the latter nucleus is given if the steady flow input rate to it is specified. The solution of the equations is simplified owing to the progressive nature of the flow; each row of nuclei of specified $Z$ receives nuclei by beta decay of nuclei $Z - 1$ and emits nuclei to $Z + 1$ by beta decay. Therefore the network may be solved one row of $Z$ at a time as the input to it from the preceding row becomes established.

Within the constraints of the steady flow approximation, the solution to Equations (1) throughout the flow network will give an exact solution. This means that the solutions should give good local representations of portions of the network after the flows have been established for a reasonable number of neutron capture times. The steady flow assumption is, however, a rough approximation in the sense that though correctly taking into account the ratio of $(n, \gamma)$ capture rates to beta decay rates in individual rows of