Neutrino Induced Reactions Related to the ν-Process Nucleosynthesis of ^{92}Nb and ^{98}Tc [1]

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The neutrino (ν) process involves ν-induced reactions on various nuclei during core collapse supernovae (SNe). Huge numbers of neutrinos are emitted from a proto-neutron star in early phase of the SN. Most neutrinos escape into the space, but a small fraction of neutrinos transfer their energy to materials in outer layer of star by neutrino-nucleus interactions. This process has been proposed as the origin of some rare isotopes of light and heavy elements.

Among the many heavy elements, only the two isotopes ^{138}La and ^{180}Ta are currently thought to be synthesized primarily by the ν-process [1]. These two isotopes have similar features: they cannot be produced by either β^+, EC, or β^- decays because they are shielded against these decays.

In principle, any nuclide can be synthesized by the ν-process in SN explosions. The produced abundances, however, are usually negligibly small because of the weak interaction. Thus, the ν-process can only play a dominant role in the case of very rare isotopes that cannot be produced by other means.

In a recent work [2], we pointed out that the nuclear chart around ^{92}Nb and ^{98}Tc is quite similar to that of ^{138}La and ^{180}Ta. Although both nuclei are unstable, their half-lives are long enough to be observed on stellar surfaces or to be incorporated into meteorites.

The isotopic abundance ratio of ^{92}Nb/^{93}Nb is known to be ~ 10^{-3}–10^{-5}. This is comparable to the isotopic rations for ^{138}La/^{139}La and ^{180}Ta/^{181}Ta. An evidence of the extinct unstable isotopes of Tc has been investigated, but it has not been found yet. This suggests the abundance of ^{98}Tc is small compared with a detection limit. Therefore, it has been proposed that the two nuclei ^{92}Nb and ^{98}Tc may have a ν-process origin.

The nuclear structure of ^{92}Nb and ^{98}Tc are key ingredients for this calculation. Our scheme for describing such excited states makes use of the standard quasi-particle random phase approximation (QRPA). For the NC reactions, we generate the ground and excited states of the odd-even target nuclei, ^{93}Nb and ^{99}Ru, by applying the quasi-particle operators to the even-even nuclei, ^{92}Zr and ^{98}Ru, which are treated as the BCS ground state.

In table 1, we tabulated main relevant neutrino-induced reactions and averaged cross sections for the typical (averaged) neutrino energy given by the ν temperature used in our calculations of nucleosynthesis [2].

Reactions	$< E_k >$ [MeV]	T [MeV]	$< \sigma >$
^{98}Mo$(\nu_e, e^-)^{98}$Tc	10.08	3.2	7.77
^{98}Mo$(\nu_e, e^- p)^{97}$Mo	10.08	3.2	1.90
^{98}Mo$(\nu_e, e^- n)^{97}$Tc	10.08	3.2	0.09
^{99}Ru$(\bar{\nu}_\mu, \bar{\nu}'_\mu)^{99}$Ru	18.90	6.0	78.5
^{99}Ru$(\bar{\nu}_\mu, \bar{\nu}'_\mu n)^{98}$Ru	18.90	6.0	14.6
^{99}Ru$(\bar{\nu}_\mu, \bar{\nu}'_\mu p)^{98}$Tc	18.90	6.0	1.70
^{99}Ru$(\bar{\nu}_e, \bar{\nu}'_e)^{99}$Ru	15.75	5.0	52.1
^{99}Ru$(\bar{\nu}_e, \bar{\nu}'_e n)^{98}$Ru	15.75	5.0	10.5
^{99}Ru$(\bar{\nu}_e, \bar{\nu}'_e p)^{98}$Tc	15.75	5.0	0.92
^{92}Zr$(\nu_e, e^-)^{92}$Nb	10.08	3.2	8.92
^{92}Zr$(\nu_e, e^- p)^{91}$Zr	10.08	3.2	2.32
^{92}Zr$(\nu_e, e^- n)^{91}$Nb	10.08	3.2	0.42
^{93}Nb$(\bar{\nu}_\mu, \bar{\nu}'_\mu)^{93}$Nb	18.90	6.0	46.8
^{93}Nb$(\bar{\nu}_\mu, \bar{\nu}'_\mu n)^{92}$Zr	18.90	6.0	1.04
^{93}Nb$(\bar{\nu}_\mu, \bar{\nu}'_\mu p)^{92}$Nb	18.90	6.0	4.90
^{93}Nb$(\bar{\nu}_e, \bar{\nu}'_e)^{93}$Nb	15.75	5.0	30.0
^{93}Nb$(\bar{\nu}_e, \bar{\nu}'_e n)^{92}$Zr	15.75	5.0	0.60
^{93}Nb$(\bar{\nu}_e, \bar{\nu}'_e p)^{92}$Nb	15.75	5.0	3.92

Table 1: Averaged cross sections in units of 10^{-42} cm^2 for ^{98}Mo via CC and ^{99}Ru via NC, and ^{92}Zr via CC and ^{93}Nb via NC with the particle emission.

References

[1] Hayakawa, T. et al.: 2010, *Phys. Rev. C*, **81**, 052801(R).
[2] Cheoun, M.-K., et al.: 2012, *Phys. Rev. C*, **85**, 065807.