Maxwellian-Averaged Neutron Capture Cross-Sections and Thermonuclear Reaction Rates for 56,57,58Fe, 59Co, and 60Ni Isotopes at Astrophysical Energies

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Abstract. Initially-produced isotopes during the course of the s-process have a significant impact on the continuity and branching network of this process. Such isotopes can undergo various neutron capture mechanisms, of which (n, γ) is important. In this research, the direct, thermal, and Maxwellian-averaged cross section (MACS), as well as the astrophysical reaction rates of the radiative neutron-capture reactions, were calculated for 56,57,58Fe, 59Co, and 60Ni isotopes. At kinetic energies between \( kT = 0.037 \) and 482.3 keV, corresponding to astrophysical temperature in the range of 0.01 to 1 GK. E1 transitions of s-wave were considered with the approximations of direct non-resonant components. The obtained MACSs and hence reaction rates were based on the data from the major measured and evaluated nuclear libraries and tables and they showed very well agreements with the most recommended database and compilations. Moreover, the effect of the direct, thermal, and negative resonance cross sections on the MACS was found to be very small and exhibit a \( 1/v \) behavior overall temperatures, with a maximum at \( T = 0.01 \) GK, while the main contribution attributed to the positive resonance term, that found to dominate overall temperature range.

1. Introduction

Neutron capture reaction plays a pivotal role in nuclear physics and astrophysics, not only for its contribution to nuclear energy development but also into the nucleosynthesis of most of the heavy elements that we still observed to this day. The phenomenological picture of this topic was sketched earlier on in 1957, by each of E. Burbidge, G. Burbidge, Fowler, Hoyle[1]; and independently Cameron[2]. Soon after the discovery of the Tc element line in the spectra of a red giant star [3] and the analysis of solar system abundance distribution by Suess and Urey[4], they were able to formulate a unified scenario to explain these observations by proposing three distinct nucleosynthetic processes responsible for production of all elements between iron and bismuth, which they defined as s, r, and p processes. With, a bulk, \( \approx 99\% \), of the chemical abundant contribution emanates from a sequence of neutron capture processes that occurs with a timescale slower (s-process) or faster (r-process) than the beta decay timescale. While the remaining part, \( \approx 1\% \), is provided by another assembly, with a different reaction mechanism known as the proton capture process (p-process)[5].

However, the analysis of the solar abundance distribution by Clayton et al. and Beer and Wisshak showed in order to explain the presence of the s-process nuclei in the solar abundance, at least two
distinct s-process components must be presented. The main component responsible for providing nuclei from Y up to Pb and the weak component that accounts for syntheses the majority of s-nuclei with atomic mass from 56 up to 90[6]. Moreover, the extensive studies [7-11 and references within] of this subject over the recent three decades have also revealed that each of these two components predominates under certain conditions and environments and with different neutron source reaction: the main component, is mainly synthesized during the recurrent thermal helium pulses in asymptotic giant branch (AGB) stars, while the weak component frequently prefers conditions of higher temperature and neutron density profile that often provided by the He core and/or C shell burning in massive stars (M ≥ 8M☉)[12].

Our concern in this paper is to calculate the direct, thermal, and Maxwellian averaged cross section of the neutron capture reaction of the first five isotopes through which the weak component of s-process initiates its trajectory, namely 56,57,58Fe, 59Co, and 60Ni, as well as their reaction rate per particle pair.

2. Maxwellian-averaged cross section and reaction rate

Most neutron capture scenarios for the weak s-process component are associated with the final stages of the stellar evolution of massive stars. High temperature of ~0.3GK, and density 1000 g/cm3 in these environments provide the necessary conditions for the main neutron source reaction, 22Ne(α,n)25Mg, to be activated[12]. Accordingly, feeding this component with the required neutrons (10^6 - 10^12 cm^-3) to begin its path through a series of neutron capture by 56Fe seed nuclei. Under such circumstances, neutrons are in complete thermal equilibrium and show a Maxwellian–Boltzmann spectrum, and the reaction rate per particle pair, ⟨σv⟩, of this nucleosynthesis have to be averaged over the mean thermal velocity, νT, at temperature T[13]:

\[
\sigma^{\text{Maxw}}(kT) = \langle \sigma v \rangle / \nu_T = \int_0^\infty \sigma_{ny} \nu \Phi(\nu) d\nu / \nu_T = (2 / \sqrt{\pi}) (kT)^{-2} \int_0^\infty \sigma_{ny}(E) E e^{-E / kT} dE. \tag{1}
\]

where \(\sigma^{\text{Maxw}}\) is the Maxwellian-Averaged Cross Sections (MACS) at an energy \(E\) in center of mass frame, \(ν\) the relative velocity of neutrons and a target nuclide, \(k\) the Boltzmann constant, and \(σ_{ny}\) is the radiative neutron-capture cross section.

For more accurate calculation of \(\sigma^{\text{Maxw}}\), Beer, Voss, and Winters had reformulated the above equation into a new expression by which the integration limit of Maxwellian distribution has discrete into several energy intervals, in order to take each dominant cross section contribution separately as follow[14]

\[
\sigma^{\text{Maxw}}(kT) = (2 / \sqrt{\pi}) \left( \frac{1}{(kT)^2} \right) \times \left[ J_1 + J_2 + J_3 + J_4 + J_5 + J_6 \right]; \tag{2}
\]

\[
J_1 = \int_{E_i}^{E_f} \sigma_{th}(E_i / E)^{1/2} E e^{-E / kT} dE;
\]

\[
J_2 = \int_{E_i}^{E_f} \sigma_{BW}(nr) E e^{-E / kT} dE;
\]

\[
J_3 = \int_{E_i}^{E_f} \sigma_{th}(E_i / E)^{1/2} E e^{-E / kT} dE + \sum_k A_{yk} E_0 k e^{-E_0 k / kT} ;
\]

\[
J_4 = \int_{E_i}^{E_f} \sigma_{ny}^{r=0.1}(sm) E e^{-E / kT} dE;
\]

\[
J_5 = \int_{E_i}^{E_f} \sigma(E) E e^{-E / kT} dE;
\]

\[
J_6 = \int_{E_i}^{E_f} \sigma(E_ε)(E_ε / E) E e^{-E / kT} dE.
\]
where $\sigma_{th}$ is the thermal cross section from the tails of positive resonances ($pr$), $\sigma_{th}^D$ the thermal direct $s$-wave capture cross section, $\sigma_{BW}$ the Breit-Wigner cross section from narrow resonances ($nr$), $\sigma_{\ell=0,1}^{nr}$ $s$- and $p$- wave neutrons capture cross section calculated by statistical model ($sm$). Whereas, the integration limits $E_i, E_f$ are the inferior and superior energy threshold for capture reaction at a given temperature $kT$, respectively, $E_x$ designates the binging of the smooth direct cross section $\sigma(E)$, $E_r$ the upper limit of the available experimental resonance cross section, $E_m$ and $E_n$, mark the gap in the excitation function which filled by the calculation of the statistical model, and $E_e$ is the experimental smooth cross section upper limit.

Hence, the astrophysical reaction rate, $RR$, and consequently the abundance of nuclides will be determined with higher precision, as the former is related to the $\sigma^{\text{maxw}}$ by the relation[15],

$$RR = 10^{-24}N_A\sigma^{\text{maxw}}(kT)\nu_T \text{ cm}^3\text{mol}^{-1}\text{s}^{-1},$$

with $N_A$ is the Avogadro’s number.

3. Direct cross section

At low energy range, the direct-neutron capture mechanism has a dominant role in total $(n, \gamma)$ cross section calculations especially in the atomic mass region around 40 and 140. Thus, to demonstrate the magnitude of its rate, the analytical formalism of Lane and Lynn for the electric dipole transitions resulting from the radiative capture of a thermal neutron is usually used. According to which, the radiative-capture cross section $\sigma(r)$ of an $s$-wave neutron with energy $E_n$ from an initial state $i$ to a $p$-orbital final state $f$ with spin $J_f$ and spectroscopic factor $S_{dp}$ can be written in the form[16]

$$\sigma_{rf}(D) = \sigma_{rf}(HS) \left[ 1 + \frac{R - a_{coh}}{R} Y_f Y_f + 2 \right]^{2}.$$

where

$$\sigma_{rf}(HS) = \frac{0.062}{R\sqrt{E_n}} \frac{Z}{A_t} \left( \frac{2J_f + 1}{6(2I + 1)} \right) \frac{\xi S_{dp}}{Y_f} Y_f \left( \frac{Y_f + 3}{Y_f + 1} \right)^2$$

$$Y_f = \left( \frac{2m_pE_f}{\hbar^2} R^2 \right)^{1/2}$$

$$= 0.2187(m_pE_fR^2)^{1/2}$$

with $R$, $a_{coh}$, $Z$, $A_t$, $m_p$, and $E_f$ are, respectively, the effective radius of the hard-sphere which would be expected to be approximately equal to the nuclear radius due to the short-range nature of the nuclear force, the free coherent scattering length, the atomic number of the target nucleus, target atomic mass number, target spin, projectile mass, and the energy of the emitted photon from the compound nucleus. While the variable $\xi$ stands for the multiplicity due to incident neutron channel spin and is given by

$$\xi = 1, \quad I = 0;$$

$$\xi = 1, \quad I \neq 0, \quad J = I \pm 3/2;$$

$$\xi = 2, \quad I \neq 0, \quad J = I \pm 1/2.$$

The Direct Capture (DC) cross section is often presented as a combination of two terms, as can notice from equation (1), the hard sphere cross section term, which is a consequence of the incident neutron scattering by the nuclear potential into a bound, single-particle state, and the second term that includes the coherent length is introduced as a modifying term for the cross section due to resonance channel contributions from distant resonances. However, to determine the total DC cross section, $\sigma(D)$,
of an s-wave neutron all the contributions due to the electric dipole transitions over final states must be summed as follows,

$$\sigma_{\gamma}(D) = \sum_{I} \sigma_{\gamma I}(D).$$

(5)

4. Thermal neutron cross section

The proximity of an s-wave excited state to the neutron separation energy is the basis of the thermal neutron capture mechanism, and in most cases, its cross section is significantly dominated by the local nearby positive and/or negative energy resonances, which cause the \(\gamma\)-ray spectrum at the thermal similar to that of the resonance. Hence, the thermal neutron-capture cross section \(\sigma_{th}\) can be conveniently provided by the single level Breit-Wigner formalism \(\sigma_{BW}\) that is given by[14]

$$\sigma_{BW}(E) = \left(\frac{\pi}{k^2}\right) \frac{1}{\sqrt{E}} \frac{\Gamma_{n}^{\ell} \nu_{\gamma}(E) \Gamma_{\gamma}}{(E_r - E)^2 + \left(\frac{\Gamma_{\gamma}}{\ell}\right)^2}.$$ 

(6)

where

$$\Gamma_{n}^{\ell} = \left(\frac{\Gamma_{n}(E_r)}{\nu_{\gamma}(E_r)}\right) \frac{1eV}{E_r}$$

is the reduced neutron width, \(\Gamma_{n}\) is the \(\ell\)-wave neutron width at resonance energy \(E_r\), and \(\nu_{\gamma}\) is the neutron penetrability function at an incident energy \(E\). \(\Gamma_{\gamma}\) and \(\Gamma_{\gamma}\) are, respectively, the radiative and total width of the resonance, \(g = (2I + 1)/(2I + 1)\) is the statistical weight factor for the compound and target nuclei of spin \(I\) and \(L\), respectively, and the quantity \(k\) is the incident neutron wave-number given by \(k = \left[0.06947 \left(\frac{A_t/A_t + A_p}\right)|E|\right]^{-1}\) for \(E\) in keV. \(A_t\) and \(A_p\) are the atomic weight of the target and projectile, respectively.

By substituting all the constant and quantities in equation (6) for an s-wave neutron and with the assumption of \(\Gamma\) and \(E \ll E_r\), equation (6) can be simplified into

$$\sigma_{\gamma}(E) = \frac{0.6566 \times 10^{6}(A_t + 1)^2}{\sqrt{E}} g \frac{\Gamma_{n}^{0} \Gamma_{\gamma}}{E_r^2}.$$ 

(7)

and the total \(\sigma_{th}\) at thermal neutron energy \(E = 0.0253\) eV is then satisfies the relation[17],

$$\sigma_{th} = \sigma_{\gamma}(+) + \sigma_{\gamma}(-) + \sigma_{\gamma}(B).$$

(8)

with \(\sigma_{\gamma}(+)\), \(\sigma_{\gamma}(-)\) provide the contributions of \(\sigma_{th}\) due to positive energy resonances with spins \(I + 1/2\) and \(I - 1/2\), respectively, and \(\sigma_{\gamma}(B)\) represents the negative energy resonances contributions with spins \(I \pm 1/2\), including direct capture component, all at \(E = 0.0253\) eV.

5. Calculations and discussions

The direct thermal neutron-captures cross section for \(^{56,57,58}\)Fe, \(^{59}\)Co, and \(^{60}\)Ni isotopes were theoretically calculated, listed in Table 1, for E1 transition of s-wave neutron using Eqs. (4,5), and based on the measured data of the \((d, p)\) reaction spectroscopic factors and \(E_{\gamma}\) that were extracted from the Evaluated Nuclear Structure Data File (ENSDF) \[18\]. \(a_{coh}\) was implemented from the National Institute of Standards and Technology (NIST) center for neutron research site[19]. The listed results show that the hard-sphere cross section displays a linear relationship with each of the reaction Q-value, through the dependence of the emitted photon on the former via the relation \((E_{\gamma} = Q - E_x)\) with \(E_x\) being the level excitation energy, and with the spectroscopic factor of the single-particle state.

The comparative variations in the results are attributed to the combined effect of the pairing and neutron scattering coherent length. It is shown that, the neutron capture reactions involving a target with
an odd mass number A, as for $^{57}$Fe and $^{59}$Co, have a higher cross section than those with even-A nuclei, $^{56,58}$Fe and $^{60}$Ni. Because of, as neutron incident on such a target a larger number of final states will become populated by the coupling of this neutron with an odd neutron or proton in the ground state via the pairing effect. Hence, enhancing the value of the DRC, especially for Even-Even reactions, through increasing the binding energy by re-arranging the internal nuclear structure, and consequently the reaction $Q$-value, in contrast to Odd-Odd reactions.

Although, this effect found to have small influence on DRCs calculations. The vast majority of the variations are ascribed to the disparity in $\frac{2g_{18}^+}{g_{30}^{30}/g_{30}^{42}}$. The higher the value of $\frac{2g_{18}^+}{g_{30}^{30}/g_{30}^{42}}$, the lower DCSs. This explained by, with increasing $\frac{2g_{18}^+}{g_{30}^{30}/g_{30}^{42}}$, the probability of the scattering by nuclear potential, $\frac{2g_{20}^{26}}{g_{30}^{46}}$, will dominated over the absorption scattering, $\frac{2g_{20}^{26}}{g_{30}^{28}}$, and thus lowering the probability of compound nucleus formation, as $\frac{2g_{20}^{26}}{g_{30}^{46}}=1-\frac{2g_{20}^{26}}{g_{30}^{46}}$. Therefore, reducing the DCS through diminishing the value of the second term within the brackets in equation (4).

### Table 1. The direct and hard-sphere radiative neutron-capture cross section for $^{56,57,58}$Fe, $^{59}$Co, and $^{60}$Ni isotopes at $E = 0.0253$ eV.

| Reaction       | $Q$-value (MeV) | $a_{coh}$ (fm) | $\sigma_{\gamma}$ (HS) (barn) | $\sigma_{\gamma}$ (D) (barn) |
|----------------|----------------|----------------|-------------------------------|-------------------------------|
| $^{56}$Fe(n,γ) | 7.6461         | 9.94           | 0.2717                        | 0.3853                        |
| $^{57}$Fe(n,γ) | 10.044         | 2.3            | 0.3527                        | 1.7                           |
| $^{58}$Fe(n,γ) | 5.581          | 15             | 0.1499                        | 1.6949                        |
| $^{59}$Co(n,γ) | 7.4919         | 2.49           | 0.4199                        | 1.9389                        |
| $^{60}$Ni(n,γ)| 7.8201         | 2.8            | 0.2242                        | 1.1178                        |

Alternatively, the thermal cross sections for all adopted reactions have also been calculated using the resonance parameters $E_r$, $\Gamma_r$, $\Gamma_n$, and $\Gamma$ that reported by the tables of Mughabghab et al. [17]. For both positive and negative resonance tails contributions of an s-wave neutron, according to equation (8). The results and their comparison with the previous pioneering calculations and experimental values are listed in Table 2, and they show a good compatibility with them, within a mean absolute percentage error of less than 4%. Moreover, the contribution of the partial cross sections with channel spin $(I + 1/2)$ into the total $\sigma_{\gamma}$ is fund to be much larger than those with $(I - 1/2)$ and, in most cases, it reasonably reproduces the experimental value by more than 60%. This due to the fact that the transition probability of the dipole-electric in a nucleus is proportional to the third power of the emitted photon energy, $E_\gamma^3$. And since, according to the shell model, the sub-state with higher $J^+$ value, $(I + 1/2)$, is more bound, stable, and has a lower $E_\gamma$ than the one with lower $J$. Then the transition to such a state will lead to a higher and faster transition rate. On the other hand, for nuclei having a close $Q$-value, as for $^{60}$Co and $^{60}$Ni, they found to have roughly the same contribution rate of the partial cross sections from those with spins $(I - 1/2)$ and $(I + 1/2)$, to their total thermal cross section.

### Table 2. Thermal neutron-capture cross section in unit of mb for $^{56,57,58}$Fe, $^{59}$Co, and $^{60}$Ni isotopes.

| Reaction       | Thermal cross section |
|----------------|-----------------------|
| $^{56}$Fe(n,γ) | This work              |
| $^{57}$Fe(n,γ) | $2.39 \pm 0.019$       |
| $^{58}$Fe(n,γ) | $2.5910 \pm 14$        |
| $^{59}$Co(n,γ) | $2.6063$               |
| $^{60}$Ni(n,γ)| $1.38$                 |
| $^{57}$Fe(n,γ) | $1.38$                 |
| $^{58}$Fe(n,γ) | $2.4810 \pm 0.30$      |
| $^{60}$Ni(n,γ)| $2.484$                |
| $^{57}$Fe(n,γ) | $1.3 \pm 0.01$         |
| $^{60}$Ni(n,γ)| $1.3 \pm 0.01$         |
Now, to define the MACS, the calculations were performed by integrating $J_1$, $J_2$, and $J_3$ terms of equation (2), within a lower and upper integration limits equal to $E_i = 0.037\text{keV}$ and $E_f = E_r = 482.3\text{keV}$, respectively, corresponding to astrophysical temperature range $(0.01 - 1)\text{GK}$. Determined on the basis of Eqs. (6,7) in reference [14] and with $E_k$ up to $20\text{keV}$. The contribution of each of these terms to the total $(n, \gamma)$ MACS as a function of temperature was plotted and presented in Fig. 1 for the five selected isotopes. In addition, our calculations have been also compared with the most recommended compilations and databases for the temperature of $30\text{keV}$ in Table 3, as this energy provides a reasonable estimate of the temperature at which $s$-process neutrons source reactions become activated in stars.

![Figure 1](image-url)

Figure 1. The total Maxwellian average cross section as a function of temperature (Gk) for the five isotopes adopted in this work, in addition to the contribution of each of $J_1, J_2, \text{and} J_3$ terms to its value.
As Fig. 1 demonstrate, over all energy range of interest the contributions of the direct radiative capture mechanism (dashed-dotted line) to the MACS is very low and it can be even ignored for some cases. Whereas the negative resonance on the other hand (dotted line) participate by less than 9% of the values of the MACSs at temperature 0.01Gk for all reactions, excepting $^{59}$Co MACS by more than 28%. While for higher temperature, the negative resonance term is characterized by a $1/v$ behavior. In contrast to the positive resonance (dashed line) that found to dominates the distribution over the entire energy range and especially at temperature $\geq 0.2$Gk, except $^{56}$Fe that show a minimum for almost 8keV at $T = 0.07$Gk due to the lack of resonance between 1.147keV and 12.45keV energy region.

### Table 3.
Comparison of the calculated MACS and stellar reaction rate at 30keV in unit of mb and cm$^3$. mol$^{-1}$. sec$^{-1}$, respectively, with the most recommended databases.

| Reaction | Quantity | This work | ENDF/B-VII.1 | JEFF-3.1.2 | JENDL-4.0 | ROSFOND-2010 | KADoNiS$^1$ |
|----------|----------|-----------|--------------|-------------|-------------|--------------|--------------|
| $^{56}$Fe(n,γ) | MACS | 11.6 | 11.51 | 11.48 | 11.84 | 11.51 | 19.71 |
| | RR $\times 10^6$ | 1.687 | 1.675 | 1.671 | 1.72 | 1.675 | 1.7 |
| $^{57}$Fe(n,γ) | MACS | 39.6 | 28.45 ± 0.46 | 30.24 | 30.21 | 28.45 | 40.00 |
| | RR $\times 10^6$ | 5.787 | 4.141 | 4.401 | 4.397 | 4.14 | 6.54 |
| $^{58}$Fe(n,γ) | MACS | 12.9 | 19.73 | 15.06 | 14.04 | 19.73 | 13.5 |
| | RR $\times 10^6$ | 1.885 | 2.87 | 2.19 | 2.044 | 2.87 | 1.97 |
| $^{59}$Co(n,γ) | MACS | 34.8 | 34.42 | 34.424 | 39.18 | 28.45 | 39.6 |
| | RR $\times 10^6$ | 5.081 | 5.008 | 5.008 | 5.7 | 4.083 | 5.78 |
| $^{60}$Ni(n,γ) | MACS | 26.4 | 26.74 | 28.24 | 27.9 | 28.26 | 29.9 |
| | RR $\times 10^6$ | 3.847 | 3.891 ± 0.23 | 4.109 | 4.06 | 4.112 | 4.37 |

$^1$ taken from Brown et al.[21].

Fig. 1 also displayed, that $^{60}$Ni, whose most of its abundance produced via the decay of short-lived radioisotope $^{60}$Co during the s-process nucleosynthesis, is of special interest, as it is a closed proton shell nucleus. Its shown, compared to all other selected reactions, this nucleus has a comparatively low neutron capture cross section at low energy side. This is because, generally, the targets with such a shell have widely spaced nuclear levels. Which leads to smaller radiative partial width of the exit channel, $\Gamma_r$, and hence makes the cross sections to be dominated by isolated resonances.

Also, it can be noticed from Table 3, for a temperature of 30keV, our results of MACSs and RR for the $^{56}$Fe, $^{59}$Co, and $^{60}$Ni showed excellent agreements with those values reported by the ENDF/B-VII.1 database. While that of $^{57}$Fe is very well reproduced those of KADoNiS. Even though, the $^{58}$Fe isotope shows a lower value by a factor of 1.27 from the average-value of the listed compilations. The reason for these variations in the current theoretical MACS and reaction rates values with the database values listed in Table 3, is attributed to the different choices of nuclear parameters which enter into the calculations.

### 6. Conclusions
For the five isotopes adopted in this study, and at energies relevant to astrophysical temperature, the effect of the direct, thermal, and negative resonance cross sections on the MACS was found to be very small and exhibit a $1/v$ behavior overall temperatures, with a maximum at $T = 0.01GK$. Whereas the positive resonance term, on the other hand, was found to be the main influencer on MACS values at all energies, especially at $kT = 30$keV, as the $^{22}$Ne(α,n)$^{25}$Mg neutron source is ignited and s-process takes place in
massive stars. Moreover, it also found that the MACS of \((n, \gamma)\) reaction that involved an even-A target nucleus is comparatively lower than those with odd-A, and particularly for those with a closed proton or/and neutron shell, as \(^{60}\text{Ni}\).

Furthermore, the definition of equation (3) and the demonstration of Fig. 2 show that due to the scaling of the stellar rate with \(1/\nu\), the rate is rather insensitive to temperature. Instead, it is more correlated to the cross section: isotopes of higher cross section, such as \(^{57}\text{Fe}\) and \(^{59}\text{Co}\), were found to have higher rates, but at the same time, they have a shorter mean neutron exposure time. And thus, suffer from larger destruction rates, especially at an elevated temperature where the photodisintegration processes in stellar plasmas begin to dominate and tend to convert them to more stable species. Unlike, those with lower cross section, which will enhance over that of unstable neighboring isotopes. Consequently, this explains the high natural abundance of \(^{56,58}\text{Fe}\) and \(^{60}\text{Ni}\) isotopes in the \(s\)-process abundance pattern compared to \(^{57}\text{Fe}\) and \(^{59}\text{Co}\).

![Figure 2. The astrophysical reaction rate for radiative neutron capture reaction of \(^{56,57,58}\text{Fe}\), \(^{59}\text{Co}\), and \(^{60}\text{Ni}\) isotopes as a function of temperature in Gk.](image)

7. References

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