The production of helium in Hastelloy-N as a consequence of neutron irradiation has long been recognized as a consideration in the development of Molten-Salt Reactors (MSR's). The contribution to this phenomenon from residual boron impurities in the alloy is equally well recognized, but the entire process has not been well defined because contributions from other sources, especially nickel, were not understood.

In a recent publication, the following two-step, thermal-neutron process was proposed as the mechanism for helium production from nickel.

\[
\text{58}_{\text{Ni}} n_{\text{th}} \rightarrow \text{59}_{\text{Ni}} n_{\text{th}} \rightarrow \text{56}_{\text{Fe}} + \text{4}_{\text{He}}
\]

This process seems to be more reasonable than the previously proposed fast-thermal process,

\[
\text{58}_{\text{Ni}} n_{p} \rightarrow \text{58}_{\text{Co}} n_{\text{th}} \rightarrow 
\]

for the following reasons:

1. The required value of the cross section for the (n,\(\alpha\)) reaction is much smaller, and, in fact, it agrees reasonably well with theoretical predictions.\(^3\)

2. Significant increases in the concentration of elements with mass number 56 have been observed in nickel as a result of irradiation.


However, it does not appear to me that the mechanism for excess helium production has been firmly and finally established.

Nevertheless, it is possible to estimate the impact of the postulated process on helium production in Hastelloy-N. Accordingly, the attached figure shows the buildup of helium as a function of thermal fluence on the following basis:

1. A natural boron concentration of 5 wt ppm was used. (This corresponds to about 5 atom ppm of $^{10}$B.)

2. A natural nickel concentration of 65 atom % was assumed.

3. Only the two thermal-neutron processes were considered.

The cross section values used were for 2200 m/s neutrons. Since the only value available for the $^{59}$Ni(n,$\alpha$) reaction (7.4 barns) corresponds to the 2200 m/s value for $^{58}$Ni (4.2 barns), I have evaded the issue of energy dependence. Presumably the effective values for both, as well as the value for $^{10}$B ($\sigma_{2200} = 394.0$ barns), would be reduced by 30 to 35% by averaging over a typical thermal spectrum. Thus, the absolute values presented may be high for a given fluence, but the relative values are not strongly affected.

As expected, the helium concentration from the boron reaction builds up rapidly and then levels off as all the boron is burned out. On the other hand, helium from the two-step nickel reaction starts slowly and then, because it varies as the square of the fluence, proceeds to quite high concentrations. At fluences above $\sim 3 \times 10^{22}$ nvt the helium buildup deviates from the fluence-squared dependence, primarily because of burnout of the original $^{58}$Ni. The figure shows quite clearly that the $^{10}$B reaction is predominant up to a few times $10^{22}$ nvt and that the nickel reactions take over before the fluence reaches $10^{23}$. Thus, for specimens irradiated to very low fluences to produce small concentrations of helium from $^{10}$B neutron captures, we can safely neglect the nickel reactions. Conversely, if high helium concentrations are produced (as by complete boron burnout), the nickel contribution must be included.

It may also be noted that, since helium buildup from nickel is practically unlimited, any Hastelloy-N must be protected from unlimited neutron exposure. While such protection may not be difficult to achieve, it must not be neglected.

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HELIUM PRODUCTION
IN HASTELLOY-N

\[ ^{140}B \rightarrow ^{7}Li + ^{4}He \]

\[ ^{58}Ni \rightarrow ^{57}Ni \rightarrow ^{56}Fe + ^{4}He \]

\[ \log_{10} \left( \frac{Ni_{2}/Ni_{1}}{Ni_{2}/Ni_{1}} \right) \]

\[ \log_{10} \text{(Fluence)} \]