# Letters to the Editor

## Comments on "Helium Production in Stainless Steel"

In a recent Note, Goel[1] makes the following comments and observations on my earlier publication.[2] His comments on my earlier paper are as follows:

1. I had pointed out the uncertainty in the data for the $^{59}Ni(n,\alpha)$ process derived from the helium production measurements.
2. The differences between the values for thermal $^{59}Ni(n,\alpha)^{56}Fe$ cross sections derived by me[2] and by Bauer and Kangilaski[3] can be due to differences in the starting values.
3. The reasons for my selection of a particular experimental point of Weitman et al.[4] and for my neglect of the data of Bauer and Kangilaski[3] are not evident from my paper.

The purpose of this Letter is to complete the above criticism of Goel.[1]

Both comments 1 and 2 stated above are correct. Regarding the third comment, I may mention here that I had felt that the experimental data of Bauer and Kangilaski could be in large error. This is confirmed by the presently[1] accepted value of $\sigma_2 = 12.5 \pm 1$ b, which is higher than that deduced in Ref. 3.

One interesting point that deserves mention regards the few related equations that Goel has explicitly avoided in his Note.[1]

Following the same notations as used in my earlier paper,[2] the correct expression (valid for both low and high fluences) for the two-step reaction is [Eq. (12) of Ref. 2]

$$N_{He}(t) = {}^{58}Ni(0)\left[\frac{\sigma_1 \exp(-\sigma_2\phi t) - \sigma_2 \exp(-\sigma_1\phi t)}{\sigma_2 - \sigma_1} + 1\right] \quad . \quad (1)$$

The corresponding expression given in Ref. 3 is

$$N_{He}(t) = \sigma_1\sigma_2\, {}^{58}Ni(0)\phi^2\left[\frac{t}{\phi\sigma_2} + \frac{\exp(-\phi\sigma_2 t) - 1}{(\phi\sigma_2)^2}\right] \quad . \quad (2)$$

The final equation used for fitting the helium production data at low fluences ($\sim 10^{21}$ n/cm$^2$) as used in Ref. 3 is

$$N_{He}(t) = \frac{1}{2}\sigma_1\sigma_2\, {}^{58}Ni(0)\cdot(\phi t)^2 \quad . \quad (3)$$

[1]B. GOEL, *Nucl. Sci. Eng.*, **69**, 99 (1979).

[2]S. GANESAN, *J. Nucl. Mater.*, **62**, 329 (1976).

[3]A. A. BAUER and M. KANGILASKI, *J. Nucl. Mater.*, **42**, 91 (1972).

[4]J. WEITMAN, N. DÅVERHÖG, and S. FARVOLDEN, *Trans. Am. Nucl. Soc.*, **13**, 557 (1970).

It is a trivial mathematical exercise to show that both Eqs. (1) and (2) reduce to Eq. (3) at low fluences. Equations (1), (2), and (3) give numerical values of $N_{He}(t)$ within 0.5% at low fluences ($\sim 10^{21}$ n/cm$^2$). However, use of Eq. (2) or (3) leads to larger errors at higher fluences, and beyond some value of the fluence, they even become physically unacceptable, i.e., $N_{He}(t)$ becomes greater than $^{58}Ni(0)$, which is not physically possible.

May I add that since the revised evaluation of $\sigma_2$ given by Goel[1] is $12.5 \pm 1$ b, the expression given in my paper[2] [Eq. (13) in Ref. 2] for the number of atoms of helium per gram of natural nickel corresponding to a thermal fluence $\phi t$ also becomes modified accordingly, as a numerical value of $\sigma_2 = 13.62$ b was used in my paper to obtain that expression [Eq. (13) of Ref. 2].

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## Remarks on "Comments on 'Helium Production in Stainless Steel'"

The earlier publication of Ganesan[1] was to explain the "fallacy in the evaluation" by Bauer and Kangilaski,[2] and it creates the impression that the low value for the thermal $^{59}Ni(n,\alpha)^{56}Fe$ cross section given by Bauer and Kangilaski is due to approximations used by them. However, it turns out that the approximations used by them are quite good[3] and the higher value of Ganesan is not due to the use of "correct" equations but due to a different data base.

In fact, the equation of Ganesan [Eq. (1) of Ref. 4] is itself an approximation. It does not account for the removal of $^{58}Ni$ or $^{59}Ni$ by processes other than those directly involved in the $^{58}Ni(n,\gamma)^{59}Ni(n,\alpha)^{56}Fe$ process. A rigorous equation has been given by Birss and Ellis[5] as

$$N_{He}(t) = {}^{58}Ni(0)\sigma_1\sigma_2\left[\frac{\exp(-\sigma_2^R\phi t)}{(\sigma_2^R - \sigma_1^R)\sigma_2^R} - \frac{\exp(-\sigma_1^R\phi t)}{(\sigma_2^R - \sigma_1^R)\sigma_1^R} + \frac{1}{\sigma_1^R\cdot\sigma_2^R}\right] ,$$

[1]S. GANESAN, *J. Nucl. Mater.*, **62**, 329 (1976).

[2]A. A. BAUER and M. KANGILASKI, *J. Nucl. Mater.*, **42**, 91 (1972).

[3]B. GOEL, *Nucl. Sci. Eng.*, **69**, 99 (1979).

[4]S. GANESAN, *Nucl. Sci. Eng.*, **72**, 121 (1979).

[5]I. R. BIRSS and W. E. ELLIS, *Proc. Br. Nucl. Soc. Conf. Voids Formed by Irradiation of Reactor Materials*, p. 339, Reading University, March 24-25, 1971, British Nuclear Energy Society (1971).

where $\sigma_1$ and $\sigma_2$ are the cross sections for the two-step process and $\sigma_1^R$ and $\sigma_2^R$ are the total effective removal cross sections for $^{58}$Ni and $^{59}$Ni. This equation reduces to the Ganesan equation by putting $\sigma_1^R = \sigma_1$ and $\sigma_2^R = \sigma_2$.

Birss and Ellis[5] have analyzed their own data and those of Weitman et al.[6] They extracted a value of 12.9 b for the thermal $^{59}$Ni$(n,\alpha)$ cross section from the data of Weitman et al.[6] Their analysis, in contrast to that of Ganesan, was not confined to one data point only. Their work was published prior to that of Bauer and Kangilaski.

It need not be mentioned that the use of approximations outside their validity limits may give results not physically possible.

[6]J. WEITMAN, N. DÅVERHÖG, and S. FARVOLDEN, *Trans. Am. Nucl. Soc.*, **13**, 557 (1970).

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