Letters to the Editor

Futher Comments on "Helium Production in Stainless Steel"

The remarks published by Goel[1] necessitate this communication to put down a few facts in a correct and complete manner. I am most grateful to Goel, who generously commented on an earlier version of this Letter.

1. On p. 122 of Ref. 1, Goel states: "It need not be mentioned that the use of approximations outside their validity limits may give results not physically possible."

In our particular context[2-7] this needs to be answered as follows: In their paper, Bauer and Kangilaski[4] state in the abstract: "Experimentally, the helium content is observed to increase as the square of the fluence, i.e., $N_{He} \propto (\phi t)^2$. It is estimated that this dependence gradually changes above a fluence of 10^{23} n/cm^2 to a linear dependence [i.e., $N_{He} \propto (\phi t)$] that becomes effective above $\sim 10^{25}$ n/cm^2." The second statement, i.e., $N_{He} \propto (\phi t)$ is wrong. This error has occurred in Ref. 4 *as a result of the fallacy of analytically approximating at higher fluences an expression that itself was valid at low fluences only*.

2. Birss and Ellis[6] clearly state in their paper that they use for the analysis of the data of Weitman et al.[5] only the approximate equation [Eq. (3) of Ref. 2] after verifying its applicability in their analysis. Their different value of σ_2 is again due to the different data base used in their analysis. Goel[1] observed that I had confined my analysis in Ref. 3 to one data point only, i.e., to the fluence $\phi t = 10^{21}$ n/cm^2. At this *same* fluence, Weitman et al.[5] give five experimental values according to Fig. 1 in Ref. 4. I had chosen the largest value of $N_{He}(\phi t)$ in my analysis.[3] I believe that the other lower experimental values of the helium produced at the same fluence as reported by Weitman et al.[5] are likely to be less correct, as helium escapes easily during detection. Birss and Ellis[6] have analyzed a large number of experimental points in contrast to my selected fluence point and their work is thus statistically far superior to my calculation of σ_2 if one assumes that the relative systematic error is the same for all the data points. (The one relative systematic error for example can be the relative amount of helium that escapes detection in each measurement. This speculation about the error is not unconventional and cannot be dismissed unless supported by experimental investigations.)

3. Goel states on p. 100 of Ref. 7: "Major helium producing constituents of stainless steel are iron, chromium, and nickel, and in some steels also boron and nitrogen."

Paulsen et al.[8] also quote Goel's Note[7] and imply that chromium, iron, and nickel are the main helium producing constituents of stainless steel.

My experience[9] has indicated that chromium does not contribute a major amount and, in fact, in most of the stainless steels the amount contributed by some of the impurities (silicon, nitrogen, boron, lithium, etc.) far exceeds that contributed by chromium. The calculations made by Kerr et al.[10] have also revealed that chromium, which is one of the major constituents of stainless steel, is *not* a major *helium producing* constituent of stainless steel and typically contributes <5% to helium production.

The calculation of impurities' contribution to helium production in stainless steel is uncertain as only upper bounds for many of the impurities are specified by the designers.

The implication is that chromium is not to be given a priority in (n,α) cross-section measurements in our context relative to other major helium producing constituents of stainless steel (iron, nickel, silicon, nitrogen, boron, lithium, etc.).

4. On p. 100 of Ref. 7, Goel refers to the charged particle simulation experiments and states: ". . . an adequate knowledge of gas production cross sections is indispensable for a reliable prediction of radiation damages."

One wonders to how much accuracy, say 10 or 40%, the (n,α) cross sections should be known, especially with the "impurities" contributing a significant amount[9,10] to the helium production in stainless steel. Attempts to quantify the required *target accuracy* for these (n,α) cross sections do not exist at present. Such a determination of target accuracies may follow, for instance, the approach given in Ref. 11, but it

[1]B. GOEL, *Nucl. Sci. Eng.*, **72**, 121 (1979).

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

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

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

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

[6]I. R. BIRSS and W. E. ELLIS, "A New Source of Helium in Cladding Materials," *Proc. Conf. Voids Formed by Irradiation of Reactor Materials*, Reading University, March 24-25, 1971, p. 339, British Nuclear Energy Society (1971).

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

[8]A. PAULSEN et al., *Nucl. Sci. Eng.*, **72**, 113 (1979).

[9]S. GANESAN, "On the Cross Section Requirements for the Prediction of Gas Production Rates for Use in Irradiation Damage Studies in LMFBR," *Proc. Natl. Symp. Radiation Physics*, Mysore, India, June 1976, Vol. XXVI, p. 261, University of Mysore (1976).

[10]H. T. KERR, M. J. BELL, and E. E. BLOOM, "Neutron Cross-Section Data Applied to the Materials Irradiation Studies at ORNL," *Proc. Third Conf. Neutron Cross Sections and Technology*, Knoxville, Tennessee, March 15, 1971, CONF-710301, **2**, 485, U.S. Atomic Energy Commission (1971).

[11]C. R. WEISBIN et al., *Nucl. Sci. Eng.*, **66**, 307 (1978).

must fully take into account the current status of the quantitative aspects of the influence of helium on the radiation damage in the reactor and on the charged particle simulation conditions. Recent experimental results,[12] for instance, do not favor the assumption of the validity of helium pre-injection in radiation damage simulation studies. I am mentioning this important point because helium production via ^{59}Ni gains importance[7,13] only at higher fluences, i.e., after ~18 months, when the fuel assembly has absolved one-half of its residence time in the SNR-2 reactor. Helium plays an important role in stabilizing the small voids that nucleate in the initial stages of void formation. The helium that would have been produced by major constituents other than nickel and by the impurities with high cross sections in these first 18 months may well dictate the stabilization of voids, etc., in the stainless steel. There are several other factors as well that influence the final state of irradiation damage. Therefore, Goel's final recommendation on p. 104 of Ref. 7 that "... in future work to calculate the helium production rate in nickel-based stainless steel, one should take the details of the neutron flux into account" should be correctly weighed in the light of these facts.

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[12]N. H. PACKAN and K. FARRELL, *Trans. Am. Nucl. Soc.*, **33**, 290 (1979).

[13]B. GOEL, "Importance and Status of (n,α) Cross Sections for a Reliable Prediction of Radiation Damage in Stainless Steel," KFK-2473, Kernforschungszentrum Karlsruhe (1977); see also, B. GOEL, *Proc. NEANDC-NEACRP Specialists Mtg. Neutron Data of Structural Materials for Fast Reactors*, Geel, December 5-8, 1977, p. 292, Pergamon Press, Ltd., London (1977).

Response to "Futher Comments on 'Helium Production in Stainless Steel' "

In his Letter, Ganesan[1] attempts to defend his earlier publications.[2-4] Since some of the formulations published by me[5,6] in this journal are criticized, a short reply from my side is demanded. I am sorry that the discussion could not be finished by private communication. My brief comments to Ganesan's remarks are as follows:

1. Ganesan's finding is not in contradiction to my statement quoted by him.

2. Ganesan emphasizes that Birss and Ellis[7] have used "only the approximate equation" after verifying its validity. This is a sound approach in analyzing experimental data. I do not see what objection Ganesan has to this approach. His discourse on the correctness of the largest of the measured values need not be commented on. It lacks any foundation. In fact, the value (2×10^{17} atoms of helium per gram of nickel for a fluence of 10^{21} n/cm^2) used by Ganesan for his analysis[2] is even higher than the largest measured value by Weitman et al.[8] for helium production in nickel (Fig. 1).

3. Impurities are not common to all types of stainless steel. Their exact concentration and spatial distribution are often unknown. Moreover, impurities with high reaction cross section are likely to be burned out in the initial phase of reactor operation; boron, for example, is almost completely consumed at a fluence of 10^{21} n/cm^2 (Fig. 1). For contribution to the helium production due to different constituents including impurities for Type 316 stainless steel, reference is made to Table 3 of Ref. 9.

4. Here Ganesan is right. I have not quantified target accuracies for the (n,α) cross section. I welcome the work at Ganesan's laboratory on quantifying these accuracies. I only hope he uses all relevant information without any bias in his analysis. The long-term helium production may remain important for certain aspects of radiation damage.

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[1]S. GANESAN, *Nucl. Sci. Eng.*, **76**, 371 (1980).

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

[3]S. GANESAN, "On the Cross Section Requirements for the Prediction of Gas Production Rates for Use in Irradiation Damage Studies in LMFBR," *Proc. National Symp. Radiation Physics*, Mysore, India, June 1976, Vol. XXVI, p. 261, University of Mysore (1976).

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

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

[6]B. GOEL, *Nucl. Sci. Eng.*, **72**, 121 (1979).

[7]I. R. BIRSS and W. E. ELLIS, "A New Source of Helium in Cladding Materials," *Proc. Conf. Voids Formed by Irradiation of Reactor Materials*, Reading University, March 24-25, 1971, p. 339, British Nuclear Energy Society (1971).

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

[9]B. GOEL, "Importance and Status of (n,α) Cross Sections for Reliable Prediction of Radiation Damage in Stainless Steel," *Proc. NEANDC-NEACRP Specialists Mtg. Nuclear Data of Structural Materials for Fast Reactors*, Geel, December 5-8, 1977, pp. 292 and 807, Pergamon Press Ltd., London (1977).