ATTACHMENT

Mr. Robert Hermann
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

January 26, 1996

Dear Bob:

I have reviewed the memorandum from Jack Rosenthal to Jack Strosnider dated October 20, which suggests that an error was made in the crack growth calculations which were carried out for the cracked head penetration at D. C. Cook Unit 2, and reported in WCAP 14118 Rev. 1, dated October 1994. The conclusions of this memorandum are incorrect, and the purpose of this note is to set the record straight.

There are three independent confirmations which we have completed to confirm the crack growth law used in the D. C. Cook evaluation.

1. The so-called Scott law as originally published in 1991 [1] contains an error which we discovered and verified through direct contact with Peter Scott.

2. As part of the Joint Owners Group activities, Brian Woodman reviewed the same data base used by Peter Scott, and independently derived a curve which is nearly identical with Scott's crack growth law, although it has a different equation.

3. Crack growth rate testing of actual head penetration materials have provided direct confirmation of this crack growth law. The latest results were published as reference 5 of the note which is attached.

These three independent confirmations were not clearly explained in the WCAP report, so the people at EG&G who reviewed the report were not aware of the error in Scott's original publication. The attached note should clear up the confusion.

Warren H. Bamford

DEVELOPMENT OF A CRACK GROWTH RATE MODEL FOR ALLOY 600 HEAD PENETRATIONS IN PWR ENVIRONMENT

The effort to develop a reliable crack growth rate model for Alloy 600 began in the Spring of 1992, when the Westinghouse Owners Group was developing a safety case to support continued operation of plants. At the time there was no available crack growth rate data for head penetration materials, and only a few publications existed on growth rates of Alloy 600 in any product form.

The best available publication was found to be that of Peter Scott of Framatome, who had developed a growth rate model for PWR steam generator materials [1]. His model was based on a study of results obtained by McIlree and Smialowska [2] who had tested short steam generator tubes which had been flattened into thin compact specimens. His results are shown in Figure 1. Upon study of his paper there were several ambiguities, and several phone conversations were held to clarify his conclusions. A record of one of the phone calls is Attachment 1. These discussions led to Scott's admission that reference 1 contains an error, in that no correction for cold work was applied to the McIllree/Smialowska data. The correct development is below.

An equation was fitted to the data of reference [2] for the results obtained in water chemistries that fell in within the standard specification. Results for chemistries outside the specification were not used. The following equation was fitted to the data:

$$\frac{da}{dt} = 2.8 \times 10^{-11} (K-9)^{1.16} \text{ m/sec}$$

where K is in $MPa\sqrt{m}$. This curve is plotted as the top curve of Figure 1, which unfortunately contains a typographical error in the label.

The next step described by Scott in his paper was to correct these results for the effects of cold work. Based on work by Cassagne and Gelpi [3], he concluded that dividing the above equation by a factor of 10 would be appropriate to account for the effects of cold work. This step was inadvertently omitted from Scott's paper, even though it is discussed. The crack growth law for 330°C then becomes:

$$\frac{da}{dt} = 2.8 \times 10^{-12} (K-9)^{1.16} \text{ m/sec}$$

This equation was verified by Scott in a phone call, which is summarized in Attachment 1.

Scott further corrected this law for the effects of temperature, but his correction was not used in the Owners Group model. Instead an independent temperature correction was developed based on service experience. This correction uses an activation energy of 33 kCal/mole, which gives a smaller temperature correction than that used by Scott (44 kcal/mole).

Scott's crack growth law is shown for 330°C in Figure 1, and this law was independently obtained by B. Woodman of ABB-CE, who went back to the original data base, and did not account for cold work. His equation was of a slightly different form:

$$\frac{da}{dt} = 0.2 \exp [A + B \ln \{\ln (K-Q)\}]$$

Where A = -25.942
B = 3.595
Q = 0

This equation is nearly identical with Peter Scott's original model uncorrected for cold work, as shown in Figure 2. This work provided an independent verification of Scott's work.

The final proof of the usefulness of Peter Scott's model comes from actual data from head penetration materials. A testing program has been underway at Westinghouse since early 1993, and to date 15 heats have been tested in carefully controlled PWR environment. The results of the program to date are published in reference [5], which is attached. One heat did not crack, and of the fourteen heats where cracking was observed, the growth rates observed in twelve were bounded by the Scott law, as shown in Figure 3. Two heats cracked at a faster rate, and the explanation for this behavior is being investigated. These two heats are different both in source and product form from those in the D. C. Cook Unit 2.

The fourteen heats tested represent material from six different fabricators of head penetration materials. The materials closest to the D. C. Cook penetrations are the forgings from Creusot in France. Three French heats have been tested to date and all three were bounded by the Scott model.

Therefore the model used for crack growth prediction has a strong technical basis, as well as a solid experimental basis. The crack growth rate testing program is expected to continue into 1997.

REFERENCES

[1] Scott, P. M., "An Analysis of Primary Water Stress Corrosion Cracking in PWR Steam Generators," in Proceedings, Specialists Meeting on Operating Experience With Steam Generators, Brussels Belgium, September 1991, pages 5, 6.

[2] McIlree, A. R., Rebak, R. B., Smialowska, S., "Relationship of Stress Intensity to Crack Growth Rate of Alloy 600 in Primary Water," Proceedings International Symposium Fontevraud II, Volume 1, p. 258-267, September 10-14, 1990.

[3] Cassagne, T., Gelpi, A., "Measurements of Crack Propagation Rates on Alloy 600 Tubes in PWR Primary Water," in Proceeding of the 5th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors," August 25-29, 1991, Monterey, California.

[4] Personal Communication, Brian Woodman, Combustion Engineering, October 1993.

[5] Foster, J. P., Bamford, W. H., and Pathania, R. S., "Initial Results of Alloy 600 Crack Growth Rate Testing in a PWR Environment" in Proceedings, Seventh International Symposium on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, August 1995.

FIG. 1 Crack Growth Equations for Alloy 600 Steam Generator Tubing

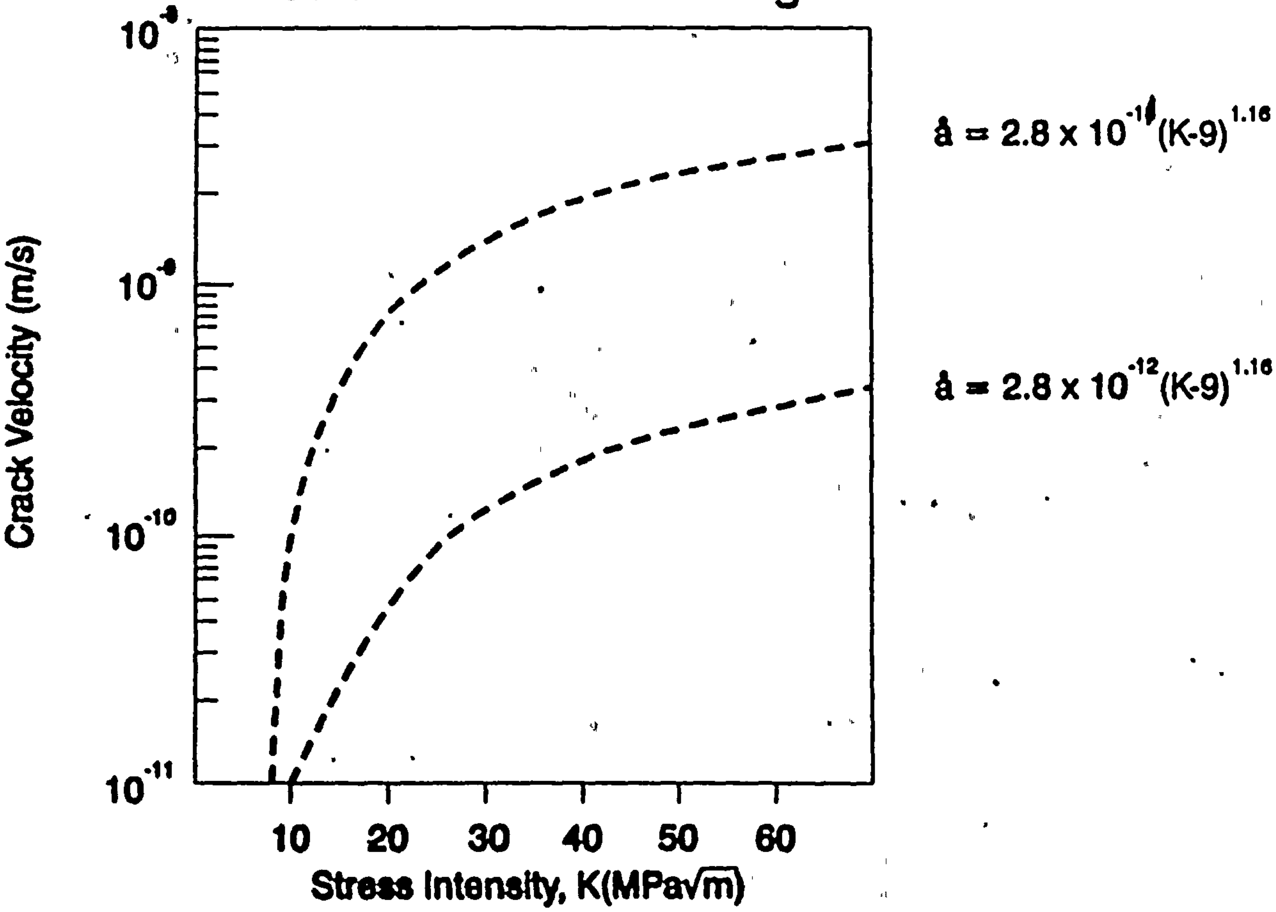
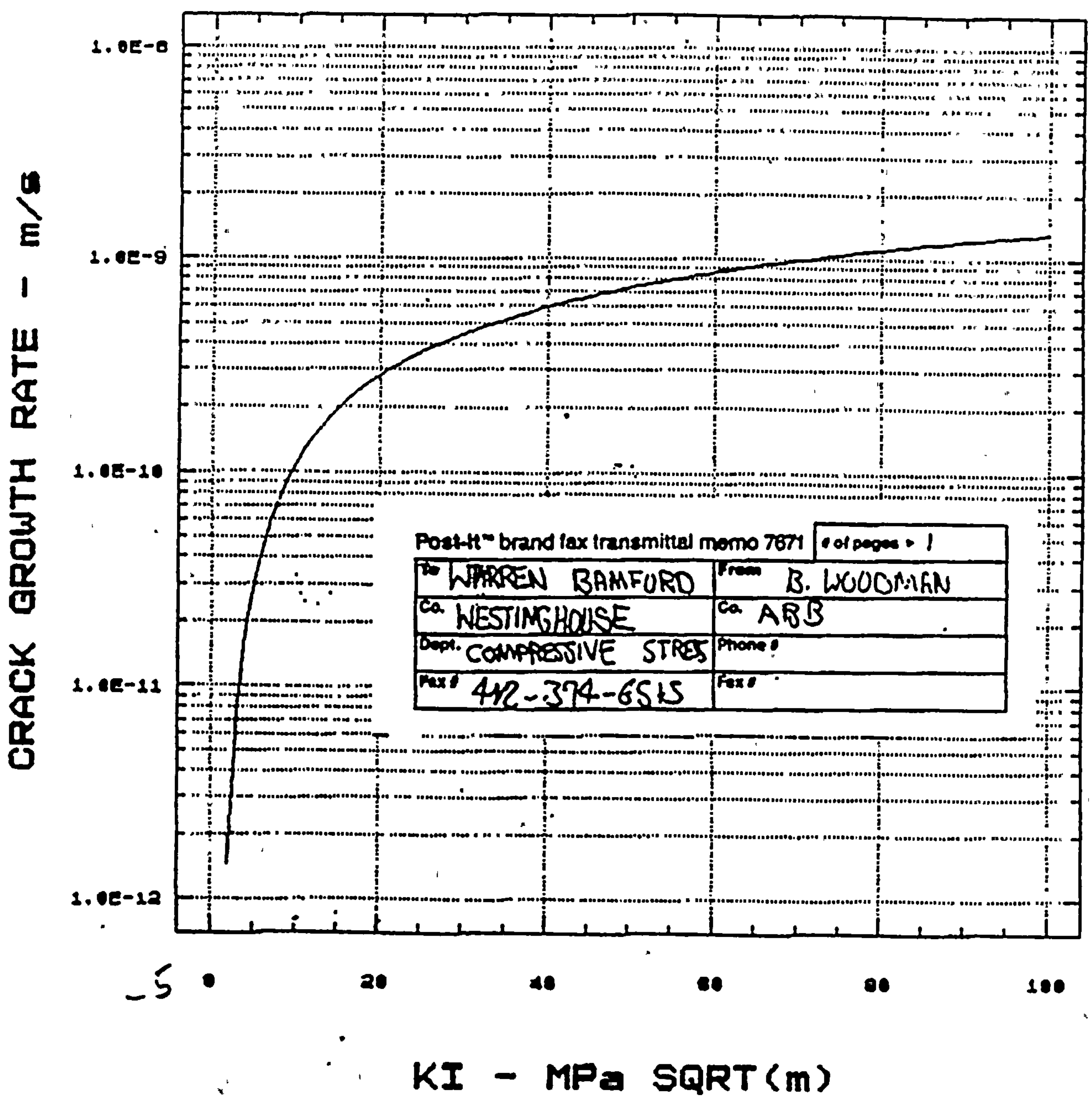


Figure 1. Scott's Alloy 600 Crack Growth Model [1]
Note the typographical error in the upper curve caption.

CRACK GROWTH RATES IN ALLOY 600

AT 626 DEGF (330°C)



(NO CORRECTION FOR COLDWORK)

Figure 2. Woodman's Independently Developed Alloy 600 Crack Growth Model [4]

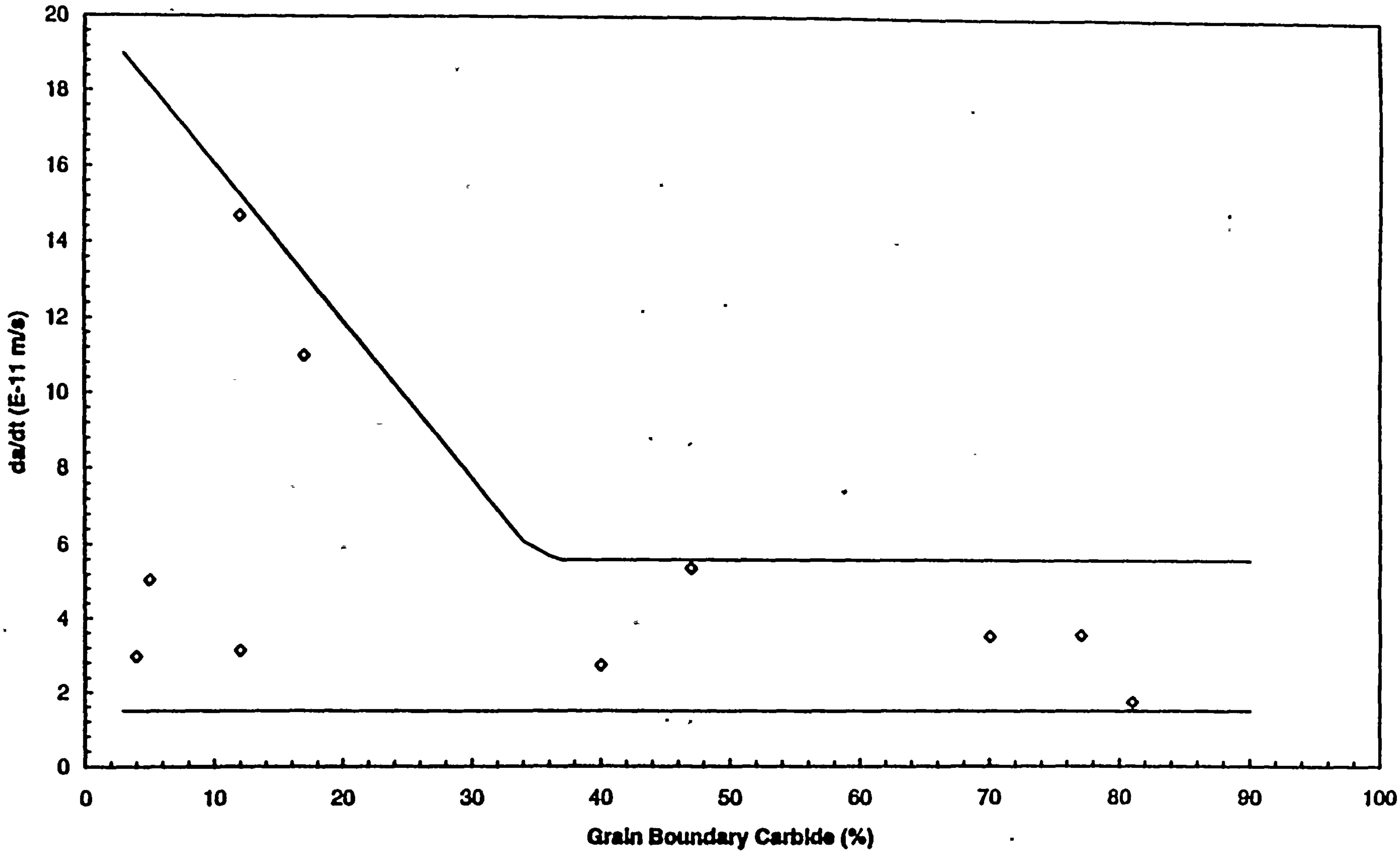


Figure 3. Summary of Available Crack Growth Data for Alloy 600 Head Penetration Materials, Compared to Scott's Model [5]

Attachment 1

July 17, 1992

I spoke with Peter Scott of Framatome this morning (July 15, 1992) concerning some questions that Bob Gold and I had regarding PWSCC growth rates for Alloy 600. Peter had published a paper at the steam generator specialists meeting in Brussels in 1991 using laboratory growth rates to model propagation of PWSCC in steam generator expansion transitions. This same analysis has been also applied to CRDM penetrations.

The main questions that we had are:

1 - Does Peter consider the McIlree/Smialowska/Rebak OSU/EPRI data to be the best data to use? Did he use the initial data presented at the Sept. 1990 Fontevraud 2 Conference or the data presented at the August 1991 ANS meeting in 1991 for his analysis?

2 - It appears that Peter had made an extreme temperature correction for PWSCC growth. He appears to have used an activation energy of over 80 kcal/mole to adjust Smialowska's data. Does he have a basis for this extreme value?

Scott used the OSU/EPRI data because it was published and available. He looked at all the data generated at 330 deg C and tried to draw an upper bound. He used the version of the data published in the ANS 1991 Monterey conference but only used data representative of realistic primary water conditions.

His adjustment of this data by a factor of 5 to 10 was not a temperature correction but rather a reality correction. That is, the OSU data was a factor of 5 to 10 times higher than data inferred from PWR steam generator experience. So Peter divided the Smialowska data by a factor of 10 to get it closer to reality. He feels that the very high values found by the OSU/EPRI researchers probably reflects the extreme cold work in making flat crack growth specimens. Data generated by Framatome/Unirec indicated that 5% cold work can influence initial PWSCC rates substantially, so he thought that this correction factor was warranted.

The equation he has been using for PWSCC growth in primary water at 330 deg C is:

$$da/dt = 2.8 \times 10^{-12} (K-9)^{1.16} \text{ m/s}$$

where K is defined in MPa m^0.5

To adjust for different temperatures, Framatome does so by using an activation energy of 44 kcal/mole. There is no exact basis for this

correction. Framatome conducted a literature review and concluded that the temperature dependence for initiation and propagation are similar and don't warrant a separate treatment. Framatome and EdF use a 44 kcal/mole activation energy rather than the 50 kcal/mole used by Westinghouse. [Note that the activation energy used by the French is about midway between the 35 kcal/mole value determined from Jim Begley's "data plot" for propagation, and the 50 kcal/mole we use for initiation. Also, a "literature review" would be expected to be about as useless as Peter found it to be.]

For expansion transitions in roll-expanded SG tubing, Framatome considers stress intensity ranges of 14 to 30 MPa m^0.5 realistic.

For CRDM applications, Framatome considers crack geometries with an aspect ratio of 3 to 1 and stress intensities in the range of 30 to 60 MPa m^0.5.

Based on this data, growth rates of 1.0 to 2.7 mm/cycle are predicted (assuming a 7000 h fuel cycle at 315 deg C). Framatome has presented to French safety authorities a rate of 3 mm/cycle. The safety authorities have not accepted that value and say it may be in the range from 6 to 9 mm/cycle.

Scott said that actual data on real penetration material was sorely lacking and should be developed over the stress intensity range of interest for penetrations.

I asked him if he thought that the cold work associated with the ovalization near the CRDM welds should be accounted for and he did not think that the 1 to 2% cold work would have nearly the effect as the 5% cold work introduced by Unirec and OSU.

Rich Jacko