LETTERS TO THE EDITOR

RECOMMENDATIONS FOR THE CALCULATION OF MATERIALS IRRADIATION EXPOSURE

At a specialists' meeting on radiation damage units, held at Harwell, United Kingdom, November 2-4, 1976, within the program of the International Atomic Energy Agency (IAEA) International Working Group on Reactor Radiation Measurements (IWGRRM), recommendations were endorsed by the international group of experts attending the meeting. Publication of these recommendations in *Nuclear Technology* will assist in their dissemination throughout the nuclear community and in achieving standardization of atomic displacement calculations by groups in different countries.

RECOMMENDATIONS FOR THE CALCULATION OF MATERIALS IRRADIATION EXPOSURE

Continued use of the 1972 recommendations on atomic displacement calculations in metals[1] is recommended with the following clarifications. Comparisons have shown that two sets of damage energy cross sections for iron, chromium, and nickel (and hence steels), calculated according to these recommendations and based, respectively, on UKNDF (Ref. 2) and ENDF/B-IV (Ref. 3) reaction cross-section files, agree to within adequate accuracy[a] when applied to fission reactor spectra. Since there is no sound basis or practical significance for selecting one set over the other, it is recommended that one or the other be used for displacement per atom (dpa) calculations. It is recommended that the Neutron Data Centers at Brookhaven, Obninsk, Saclay, and Vienna be asked to maintain and make available the above damage cross sections in the 31-group MUFT structure and, in the case of the Ref. 2 data, in the 621-group SAND-2 structure as well.

Comparisons of damage energy cross sections for zirconium tabulated in Refs. 1 and 2 exhibit unsatisfactorily large discrepancies that must be resolved. In the interim, it is recommended that both damage energy cross sections also be made available. It is further recommended that the conversion from damage energy to displacements for zirconium follow the same prescription as for iron.

No damage energy cross sections are recommended at this time for application to neutron spectra harder than a fission spectrum, such as are of interest in fusion reactor development programs. Further comparisons of cross-section sets extending to high energies must be made. It is recommended that within the next two or three years, exchanges of reevaluated damage energy cross sections be made with the objective of resolving remaining differences.

In conclusion, we recommend the continued use of dpa as a spectrum sensitive measure of a material's irradiation exposure but would emphasize that dpa should not be interpreted as a direct measure of actual defect damage in the material.

[a]The agreement for nickel and iron is within a few percent; the agreement for chromium is somewhat poorer, but the discrepancy is negligible in applications to stainless steels.

RECOMMENDATIONS FOR THE ATOMIC DISPLACEMENT CALCULATIONS IN METALS

These recommendations apply to atomic displacement calculations in metals. A principal objective is the formation of a basis for the uniform reporting of neutron and other particle irradiation damage exposures in the study of irradiation effects in metals. We make the following recommendations:

1. For all irradiations, the experimental conditions and how they were determined should be fully specified. This includes:

   a. the reactor and location within the reactor, the neutron flux, the neutron spectrum, and the irradiation time and temperature, or

   b. the ion species, the ion energy and particle flux, the irradiation time and temperature, the method of irradiation (scanning, rocking, etc.), the depth at which the sample is taken, and the sampling thickness and crystal orientation where relevant, or

   c. the electron energy, the displacement cross section, the electron flux, the irradiation time and temperature, the foil thickness, and crystal orientation.

2. In addition to the above data, we recommend that the irradiation exposure be quoted in terms of dpa, using the following interim procedure for calculating secondary displacements[4]:

$$N_d = \beta E_{\text{Damage}} \;, \qquad \text{displacements/primary} \;,$$

where $\beta = 10\ \text{keV}^{-1}$ for iron, steels, and nickel-based alloys and E_{Damage} is an estimation of energy deposited into atomic processes given by

$$E_{\text{Damage}} = \frac{E}{[1 + kg(\epsilon)]}$$

$$k = 0.1337\, Z^{2/3}/A^{1/2}$$

$$\epsilon = E/[86.931\, Z^{7/3}] \qquad (E \text{ in eV}) \;,$$

where Z and A are the atomic and mass numbers, respectively.

For neutron irradiation, the relevant neutron cross section, the reaction kinematics, and spectral data used for calculating the primary recoil spectrum should be referenced. In the case of ion bombardment, the method of calculating the energy deposited into atomic processes (E_{Damage}) as a function of depth should be stated with appropriate definition of parameters.

3. Future work should include studies of the energy partition and recombination processes. Recognizing the dependence of displacement calculations on neutron interaction cross sections, we recommend that the IAEA compile and evaluate cross-section sets used in such calculations.

RECOMMENDATIONS FOR GRAPHITE

The meeting saw no reason to change the conclusions reached at the Seattle meeting in 1972, and it agreed that the recommendations made at that meeting and also published in Ref. 2 should continue to be used.

Thank you for your cooperation in publishing these recommendations.

V. Chernyshev, Scientific Secretary

International Atomic Energy Agency
International Working Group on
Reactor Radiation Measurements
A-1011 Vienna, Austria

November 11, 1977

REFERENCES

1. "Recommendations for Displacement Calculations for Reactor/Accelerator Studies in Austenitic Steel," *Nucl. Eng. Design*, **33**, 91 (1975).

2. G. P. GENTHON, B. W. HASENCLEVER, P. MAS, W. SCHNEIDER, S. B. WRIGHT, and W. L. ZIJP, "Recommendations on the Measurement of Irradiation Received by the Structural Materials of Reactors," EUR 5274, Commission of the European Communities Report (1975).

3. D. G. DORAN and N. J. GROWES, "Neutron Displacement Damage Cross Sections for Structural Metals," *Irradiation Effects on the Microstructure and Properties of Metals*, ASTM STP 611, pp. 463-482, American Society for Testing and Materials (1976).

4. M. J. NORGETT, M. T. ROBINSON, and I. TORRENS, CEA 4389, Commissariat à l'Energie Atomique, AERE TP/494, U.K. Atomic Energy Research Establishment or ORNL Solid State Division 72-70, Oak Ridge National Laboratory.

COMMENTS ON "RECENT DEVELOPMENTS IN THE DESIGN OF CONCEPTUAL FUSION REACTORS"

I have just completed reading the paper in the July issue of *Nuclear Technology* by Ribe.[1] While I am in no position to assess the correctness of the degree of optimism expressed about fusion technology or economics, I must point out that if Fig. 7 is typical of the entire article, there is a serious problem of credibility. To indicate that no current data are available on estimating fast breeder reactor costs is really absurd. One might disagree with the available numbers—either too high or too low—but a plethora of data does exist, data that are much more extensive than that existing for solar electric, coal-fired magnetohydrodynamics, or UWMAK III.

It also is not clear why oil-fired gas turbines and geothermal are shown as post-1980 when both currently exist in utility systems.

M. Levenson

Electric Power Research Institute
Nuclear Power Division
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, California 94303

August 15, 1977

REFERENCE

1. F. L. RIBE, "Recent Developments in the Design of Conceptual Fusion Reactors," *Nucl. Technol.*, **34**, 179 (1977).

REPLY TO "COMMENTS ON 'RECENT DEVELOPMENTS IN THE DESIGN OF CONCEPTUAL FUSION REACTORS' "

I can understand Levenson's concern[1] that Fig. 7 of my paper shows "no current data available" for liquid-metal fast breeder reactor (LMFBR) costs. What is meant there and in the UWMAK III report, from which Fig. 7 was taken, is that no data from Bechtel Corporation were available from their studies on advanced energy systems, of which UWMAK III is one.

However, the same page of my article does quote a fast breeder cost of 45 to 55 mill/kWh as derived in the UWMAK III report. Figure 1 (see next page) is a new version of Fig. 7 in which Conn provides an update of advanced-systems costs, including the fast breeder. The range of LMFBR costs goes from a low of 20% premium over light water reactor costs (an oft-quoted "target") to 55 mill/kWh. The value of 45 mill/kWh is obtained simply as half the estimated cost of the Clinch River Breeder Reactor based on historical trends, as quoted in Ref. 2.

F. L. Ribe

University of California
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, New Mexico 87545

September 27, 1977

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1. M. LEVENSON, "Comments on "Recent Developments in the Design of Conceptual Fusion Reactors," *Nucl. Technol.*, **37**, 359 (1978).

2. M. LEVENSON, P. M. MURPHY, and C. P. L. ZALESKI, "Economic Perspective of the LMFBR," *Nucl. News.*, **19**, *5*, 54 (1976).